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**rORAL: Plataforma computacional para a recolha e
avaliação remota de imagens em saúde oral**

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and remote assessment of images in oral health**



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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia de Computadores e Telemática, realizada sob a orientação científica do Professor Doutor Ilídio Fernando de Castro Oliveira, Professor Auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro, e da Doutora Ana Raquel Sebastião, investigadora do Instituto de Engenharia Eletrónica e Informática de Aveiro.

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palavras-chave

saúde oral, mHealth, telemedicina, computação móvel

resumo

A evolução dos dispositivos móveis e a sua disponibilidade geral criam oportunidades para o seu uso em aplicações de saúde (mHealth).

Um dos casos de uso possíveis inclui o uso dos dispositivos móveis na captura de imagens para documentar condições clínicas. Isto pode ser usado em saúde oral para permitir a avaliação remota da cavidade oral, por exemplo, para rastreios de saúde oral feitos à população.

Neste trabalho propomos uma plataforma digital que permite estudos de saúde oral, que incluem a captura de fotografias da cavidade oral com dispositivos móveis, nomeadamente smartphones, próximo do paciente usando uma aplicação móvel e a sua posterior avaliação por profissionais, usando uma aplicação web criada para o efeito.

A plataforma desenvolvida, chamada rORAL, consiste numa aplicação Android e duas aplicações web. A aplicação Android é usada para captura de fotografias. Uma das aplicações web é usada para gerir os estudos e a outra é usada para avaliar os casos clínicos.

O sistema foi implementado num protótipo funcional e validado num contexto educacional em medicina oral com prática de saúde comunitária.

keywords

oral care, mHealth, telemedicine, mobile computing.

abstract

The evolution of mobile devices and their general availability creates an opportunity for their use in mobile health scenarios (mHealth).

One of the possible use cases includes the use of mobile devices in capturing pictures to document clinical conditions. In oral care, this can be used to enable remote assessment of the oral cavity, for example, for oral health screening in the population.

In this work we propose a digital platform to enable studies in oral care, which includes the capture of oral cavity photographs with mobile devices like smartphones, near the subject of care, and the posterior review by experts, using a web application.

The proposed platform, named rORAL, consists in an Android application and two web applications. The Android application is used for image acquisition. One of the web applications is for studies management and the other is to manage worklists and to review the clinical cases.

The system has been implemented in a functional prototype and was validated in the use case of oral care education with community practice.

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List of Acronyms

REST	Representational State Transfer
DRF	Django REST Framework
API	Application Programming Interface
SDK	Software Development Kit
NDK	Native Development Kit
MVC	Model-View-Controller
HTTP	Hyper Text Transfer Protocol
FCM	Firebase Cloud Messaging
JSON	Javascript Object Notation
SUS	System Usability Scale
rORAL	name of the platform developed
rORAL-mob	name of the mobile subsystem of the platform
rORAL-PoC	name of the web-based subsystem of the platform to create and manage oral studies and their participants
rORAL-review	name of the web-based subsystem of the platform to manage worklists and clinical reporting

Chapter 1

Introduction

1.1 - Motivation

Oral diseases affect approximately 3.9 billion people in the world [1]. This group includes diseases with a wide range of severity, for example caries or tongue cancer.

Studies show that the incidence rates of different types of oral cancer are increasing in Portugal [2], and in other places like the United States¹ and the United Kingdom². Apart from the obvious health concerns coming with oral diseases, they can also impact other life aspects, namely the social dimension. Oral health influences how someone talks, chews, eats and tastes food. A bad set of teeth and a deteriorated oral health can lead to malnutrition, pain, social isolation [3] and could also influence productivity at work [4].

In older adults, oral health is sometimes neglected and a great number of diseases occur in mouth, jaws and orofacial skin/tissues; mostly traumatic, but also bacterial, viral, fungal and neoplastic, among others³. This points out the need of oral health screening in the population, namely in elderly.

The evolution of technology led to a fast increase in smartphones' computational capacity. The increasing usage of mobile data plans makes the sharing of content almost immediate. This, combined with the wide use of smartphones in society, makes possible the usage of smartphones to help tackle health issues. So, the rising technology and the easy sharing of contents can be taken advantage of by using the smartphone as a mobile camera and establishing a telehealth platform.

Teledentistry scenarios are taught in dental medicine education at the Instituto de Ciências da Saúde da Universidade Católica Portuguesa (ICS-Visau). A collaboration protocol was established with that faculty for clinical specialists to define the requirements for this platform. The education scenarios that include the consultation of elderly at nursing homes were considered as case studies for this dissertation.

¹ <https://seer.cancer.gov/statfacts/html/oralcav.html>

² <http://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/oral-cancer#heading-One>

³ https://www.cdc.gov/oralhealth/publications/factsheets/adult_oral_health/adult_older.htm

1.2 - Objectives

This work proposes a digital platform to enable studies in oral care, which include the capture of oral cavity photographs with mobile devices like smartphones, near the subject of care, and the posterior review by experts, using a web application. To demonstrate the feasibility of a remote evaluation, we aim to implement all the stages of this teledentistry model, from the image acquisition and transmission to the organization of worklists and remote evaluations.

1.3 - Main Contributions

The main contribution of this system is a telemedicine platform to screen oral diseases in elderly people and to early identify pathologies that need to be carefully diagnosed and attended by dentists.

This telemedicine platform helps in remote oral assessment. Regarding reduced mobility of patients, images can be collected locally by caregivers at day care centers and evaluated at dental services. The evaluations are then sent back to the caregivers with advice on how to provide personalized dental assistance to the patients.

1.4 - Dissertation Structure

This dissertation starts with the motivation of this work, showing why it is a relevant problem nowadays and the technological advances that make a solution possible. An overview of the main goals and contributions is also presented.

The following chapter, State of the Art, presents a brief resume of the current state of technology, previous works and relevant experiments to this dissertation.

The chapter Requirements and Use Cases describes the scenarios where a remote image assessment telemedicine platform might be used, the workflow and the actors of the system, along with the tasks they might do in it.

The following chapter is devoted to the system architecture, the different components of the system and how they communicate.

This is followed by the Implementation part, in which the main development decisions regarding the whole work are shown and explained.

Afterwards there is a section where rORAL is evaluated, presenting the pilot use of this work, the main findings taken from it and the system usability questionnaires results.

It ends with the Conclusions and Further Work chapter, with the main conclusions of the work developed and plans to further improve it.

Chapter 2

State of the Art

This section focuses on developments in technology and science that have allowed the growing of telemedicine and the uprising of mobile health (mHealth). Moreover, their previous uses in healthcare are displayed and reviewed.

2.1 - eHealth, telemedicine and mHealth

eHealth is defined as the use of information and communication technologies to enhance health care. It encompasses telemedicine and mHealth, among others. Although these three terms have similarities between them, as they all are ways to improve health care, there are characteristics that distinguish them.

Telemedicine is the use of “telecommunication and information technology to provide clinical health care from a distance” [5]. It started being used in the 1950’s, initially as the transmission of radiologic images between two health centers in Pennsylvania, United States [6]. The difference to eHealth is that Telemedicine refers only to remote clinical services, whereas eHealth encompasses that, but is not limited to it. Originally, telemedicine was used to reach patients living in remote areas and with deficient access to healthcare. This reliable solution is critical when considering reduced mobility and isolated or remote places and communities [7]. However, as the development continued, telemedicine turned out to be an opportunity to reduce costs and waiting time in healthcare in urban areas. It is also a reasonable tool for clinical second opinions.

mHealth is the use of mobile devices such as mobile phones, smartphones, tablets and smart watches for health information delivery, data collection, real-time monitoring and so on. It differs from eHealth in that it is the use of mobile devices, while eHealth is not always mobile related [8].

The increasing diffusion and usage of mobile phones and smartphones by populations and its fast-developing technology are responsible for helping the development of mHealth. In 2017 around 64.5% of people worldwide owned a mobile phone⁴, and around 33% owned a smartphone (rising to 65% in Western Europe and 64% in North America⁵). Over the recent years many new features have been incorporated into smartphones. For example,

⁴ <https://www.statista.com/statistics/470018/mobile-phone-user-penetration-worldwide/>

⁵ <https://www.statista.com/statistics/203734/global-smartphone-penetration-per-capita-since-2005/>

touchscreens, GPS, sensors and cameras. The smartphones' cameras are of special importance for the objective of this dissertation, since the quality of the images provided for the evaluators to work on heavily depends on the quality of the photographs taken by the smartphone's camera. However, it was that smartphone cameras can be a feasible substitute for digital cameras for the purposes of medical teleconsultation [9].

2.2 - Main Telemedicine Categories

There are, in general, three categories in telemedicine: store-and-forward, remote patient monitoring and real-time interactive [10].

Store-and-forward (asynchronous)

In this approach, the data (such as, x-rays, videos or oral photographs) is collected and later sent to the professionals for examination, or stored in a server from where they can access it.

One of the advantages of this method is that there is no need for the professionals and the patients to be available at the same time, therefore coordinated schedules between them are not necessary. On the other hand, it turns out to be more suitable for delay-tolerant networks, where there can be long delays and high error rates in transmission of data, which would make it unsuitable for live video calls, for example. That also gives the professional more time to make an evaluation.

The patient and the dentist can't communicate instantly like they could in face-to-face consultations or in live video calls, so the asynchronous nature of this method has the disadvantage of more delays between the capture of data and the receiving of the examination. Another constraint is that since it depends on images, documents and reports instead of physical examinations it can have a higher risk of providing less information for diagnosis.

Remote Patient Monitoring

This is an area where the patient is monitored using sensors, like heart rate sensors or glucose trackers, and the data is transmitted to the healthcare providers. That data is then used by the health professionals to act accordingly.

This approach has the advantage of a healthcare provider being able to track the patient from a distance, even after they⁶ have been discharged from the hospital, for example. It

⁶ The singular they was used in the writing of this dissertation for it to be gender-neutral. At first glance it may seem like there are mismatches in number agreement, although there aren't. There is more information on <https://en.oxforddictionaries.com/grammar/using-they-and-them-in-the-singular>

gives the patients the feeling that they are still being accompanied after the consultations, making them feel more taken care of and safer. These two things allow to decrease the number of hospitalizations and their respective durations, because the patient can be released earlier and continue to be accompanied from their own home. In particular, it has been proven that the more the patients with cardiac electronic implantable devices collaborate with remote monitoring, the more chances they have of survival [11].

The main drawback of this approach is the fact that its accuracy highly relies on the patient's collaboration. In some cases, the patient is responsible for capturing their own data, for example measuring their glucose levels, and sending them. If the patient fails on the assignments then the healthcare providers do not receive the data and cannot accompany the patient correctly.

Real-time interactive

In this approach the patients and the professionals are interacting live, for example, on a video call. This is the approach used by Denteractive⁷.

An advantage is that, since they are interacting live, the exchange of information between them (such as medication to take, advices or questions) can be much faster. They do not have to be in the same location, they can be far from each other, which means that the patient can be in the comfort of their own home.

A huge disadvantage of this method is that, because the professionals and the patient need to be available at the same time, they need to schedule one time to meet, which is not required in the store-and-forward approach. So, the network used must be reliable, otherwise the live video call would not be effective.

⁷ <https://denteractive.com>

2.3 - Teledentistry applications in oral care and education

Teledentistry is a specific area of telemedicine for dental care, consisting on the use of technology to help screen for oral diseases and generally to help providing oral care. Although telemedicine is about the clinical uses of technology, teledentistry encompasses both remote clinical and remote non-clinical uses of technology for oral care. Teledentistry has been used both as a replacement for face-to-face consultations [12] [13], to provide care for underserved populations, for screening and on education, to provide interesting and alternative ways of teaching [14].

Regarding teledentistry in education, there are two main categories: online courses and interactive video conferencing. They both provide ways to get education remotely and have produced satisfactory results [15] [16].

Interactive video conferencing consists in a several parties having a two-way communication over a live video call. One advantage is that the user (student) can receive immediate feedback [14] [17]. A study done in Finland, where university lectures were transmitted to students, concluded that video conferencing is suitable for long distance learning in dentistry and that it allows to significantly “reduce travel time and expenses” [18].

Email messages and mobile apps have been used in teledentistry, with results that show that they can increase the accuracy of remote consultations and diagnosis [19] [20]. Indeed, Whatsapp has been used to communicate between dentists and between dentists and their patients [21]. There are also some services in the United States that make use of teledentistry to bring oral care to people, such as Denteractive, OralEye⁸ and Straight Teeth Direct⁹, among others.

The end user acceptance of a teledentistry system very similar to the one proposed in our work was assessed recently [22]. Its architecture also had an Android app for image acquisition and upload, a cloud-based server that enabled data entry, data storage, data retrieval and image storage, a website to review and assess the records stored in the server, a teledental assistant to capture images of the patients and a grader (a dentist) to review the images. The telemedicine technique used was the store-and-forward. That study concluded that users considered teledentistry useful and that this area will grow steadily in the future due to the developments in smartphones and smartphone cameras [22].

Although the previous study wasn't solely focused on the accuracy of the images but on the system as a whole, there have been studies regarding the accuracy of dental images in teledentistry when compared to the most common face-to-face examinations. Some studies used photographic/videographic cameras while others used smartphone cameras. Those studies concluded that smartphone cameras could obtain results at least as good as digital

⁸ <https://oraleye.com/>

⁹ <http://www.straightteethdirect.com>

cameras, and that photographic analysis had results similar to face-to-face consultation [16] [23] [24].

All things considered, mHealth and teledentistry have been growing since mobile phones appeared. Moreover, due to the constant development in smartphones and in their cameras, to the increasing diffusion in society and the internet coverage, it will continue to grow at a fast pace.

2.4 - Image-based tele-diagnosis architectures in oral care

Image-based tele-diagnosis in oral care consists in a diagnosis based on photographs taken from the patient's oral cavity. Table 1 shows a summary of the image-based tele-diagnosis architectures analyzed.

	Who captured the images?	Device used for capturing images	Channel used for transmission of images	Who reviewed the images?	Platform used for reviewing the images
TME3/347: A teledentistry consultation system and continuing dental education via internet [13]	dentists	digital camera	secure web server	oral medicine specialists	secure web server
Teledentistry: Distant Diagnosis of Oral Disease Using E-Mails [20]	not specified	digital camera	e-mail	oral medicine specialists	e-mail
A proof-of-concept evaluation of a cloud-based store-and-forward telemedicine app for screening for oral diseases [22]	teledental assistants	smartphone camera	secure web server	oral medicine specialists	secure web server
Accuracy of Teledentistry for Diagnosing Dental Pathology Using Direct Examination as a Gold Standard: Results of the Tel-e-dent Study of Older Adults Living in Nursing Homes [24]	teledental assistants	intra oral camera	external hard drive	dental surgeon	none, they were reviewed on a laptop
Use of a Teledentistry-based Program for Screening of Early Childhood Caries in a School Setting [26]	examiner, profession not specified	intra oral camera	not specified	the same examiner that took them and another examiner	none, they were reviewed on a laptop
Dental Screening of Preschool Children Using Teledentistry: A Feasibility Study [27]	telehealth assistant	intra oral camera	secure web server	general dentist	secure web server
Performance of distant diagnosis of dental caries by teledentistry in juvenile offenders [28]	not specified	digital camera	file-sharing service and compact disc	consultant, profession not specified	not specified

Table 1 - Resume of the analyzed image-based tele-diagnosis architectures in oral care.

Of the papers found, one particular study [22] is analyzed in this chapter because it is representative and similar to the platform proposed in this work.

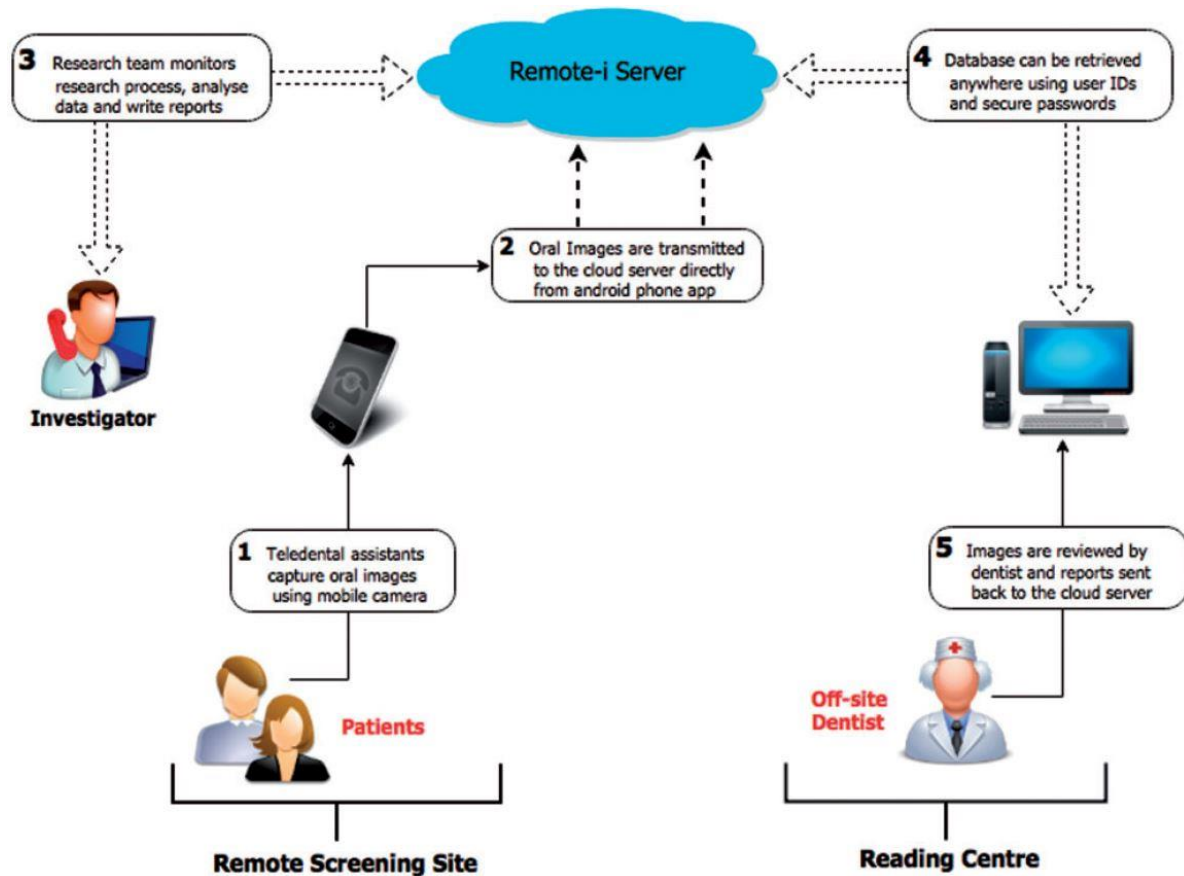


Figure 1 – Example of a teledentistry system architecture, taken from [22].

Component	Description
Remote Server	Cloud-based platform to enable data entry, storage and retrieval
Android App	App used for taking pictures, uploading them and entering patient data
Website	For the dentists to access and review the records stored in the server in a user-friendly way
Teledental Assistant	Obtains consent from the patients, creates their records in the system, takes dental photographs and uploads them into the server
Dentist (Grader)	Evaluates the records stored on the server

Table 2 - Components of a teledentistry system architecture from [22].

Figure 1 and Table 2 show the components present in the architecture of the teledentistry system described in [22]. It uses a remote server for data entry, storage and retrieval, a mobile app for image acquisition and upload for the server, a website to review and assess the records stored in the server, a teledental assistant to capture images of the patients using the mobile app and a dentist to review the images using the website. This system was used as a proof of concept to evaluate the feasibility of a store-and-forward telemedicine application for screening of oral diseases.

Figure 2 consists of two parts: (a) a paper form titled 'Dental Charting – Teledentistry Study' and (b) a digital form titled 'Details'.

Part (a) is a paper form with the following sections:

- Operator's Name & ID** and **Patient's Hospital ID*** (text fields).
- Date** and **Site** (dropdown menus).
- *Make sure this matches that used on the photo system** (note).
- Did patient visit a dental practice in the past year?** (Yes/No checkboxes).
- What was the reason for last dental visit?** (Radio buttons: Routine Check-up, Oral Problem).
- What was type of dental practice attended?** (Radio buttons: Public Clinic, Private Clinic, School Dental Service).
- Was cost a reason for delaying/avoiding a dental visit?** (Yes/No checkboxes).
- Dental Insurance** (Yes/No checkboxes).
- Dental visiting patterns** (Radio buttons: At Least One Visit/Year, Visit But Not Every Year, Do Not Visit At All).
- What was type of dental service received?** (Radio buttons: Extraction, Filling, Scale/Clean, Other).
- Was cost a reason for not receiving a recommended dental treatment?** (Yes/No checkboxes).
- Hospitalised for a dental problem in the past year** (Yes/No checkboxes).
- Dentition Status** (Grid for recording dental status).
- Deciduous Teeth** and **Permanent Teeth** (List of teeth with corresponding codes).
- Plaque Score** (Radio buttons: 0 = None, 1 = Little, 2 = Moderate, 3 = Heavy).
- Urgency Of Treatment** (Radio buttons: 0 = No treatment needed, 1 = Preventive or routine treatment needed, 2 = Prompt treatment needed (e.g. Scaling), 3 = Immediate treatment needed (e.g. Pain or Infection), 4 = Referred for medical/dental treatment).
- Final comments:** (Text field).

Part (b) is a digital form titled 'Details' with the following sections:

- Operator's Name & ID** and **Patient's Hospital ID*** (text fields).
- Date** and **Site** (dropdown menus).
- *Make sure this matches that used on the photo system** (note).
- Did patient visit a dental practice in the past year?** (Yes/No checkboxes).
- What was the reason for last dental visit?** (Radio buttons: Routine Check-up, Oral Problem).
- What was type of dental practice attended?** (Radio buttons: Public Clinic, Private Clinic, School Dental Service).
- Was cost a reason for delaying/avoiding a dental visit?** (Yes/No checkboxes).
- Dental Insurance** (Yes/No checkboxes).
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- Final comments:** (Text field).

Figure 2 – the paper form filled by the onsite dentist (left) and the digital form shown to the offsite dentist (right) (taken from [22]).

The system was evaluated by simulating screening workflows:

- each volunteer was examined face-to-face by a dentist to register caries and restorations (the gold standard). They filled the form shown on Figure 2a.
- the teledental assistant took 5 photographs of each volunteer's oral cavity using the smartphone app.
- the photographs were forwarded from the smartphone to the remote server by the teledental assistants
- the offsite dentists reviewed the stored photographs and submitted their reviews on the platform built in the remote server, using the online form shown on Figure 2b.

The evaluation made by the onsite dentist was compared with the evaluations made by the offsite dentists. The results of that comparison suggested that the reviews made by the onsite dentist were, in general, in agreement (Kappa = 70%) with the ones made by the offsite dentists [22].

This result shows that this approach to teledental screening can be used, is a reliable and trustable screening tool and a valid alternative to face-to-face examination. However, this was only a proof of concept and this test had few people involved. To take the findings further, more experiments with a larger number of people involved were performed. The authors of this study conducted another experiment [25] with the goal of finding out if the end users of the system (the teledental assistants and the graders) globally accepted this solution, as well as any recommendations for improvement that they might had.

To achieve this goal, more volunteers, teledental assistants and graders means that many more records were made. At the same time, more skilled people were involved in reviewing the data recorded. These allowed to bring more accuracy to the conclusions of this experiment. Seventeen teledental assistants and five graders participated and over six months almost 100 records, containing 485 photographs along with anonymous patient demographic data, were collected at hospitals and dental facilities and then uploaded to the server, where they were reviewed by graders.

Moreover, to find out the global acceptance of this model, a questionnaire was sent to the teledental assistants and to the graders. This questionnaire was based on the technology acceptance model (TAM). TAM is a theory that tries to predict how a user will use and accept a certain technology. It bases itself on the premise that two important factors influence how a user will interact with the system [29]. Those factors are:

- Perceived usefulness, which is "the degree to which a person believes that using a particular system would enhance his or her job performance" [30]
- Perceived ease of use, which is "the extent to which an individual believes that using a particular system is free of physical and mental effort" [31]

The answers to the questionnaire suggested that the users' perception of usefulness and of ease of use were generally high. Despite that, some users were concerned with the quality of the images captured by the smartphones [25]. Even though some users of this system suggested improvements to the smartphone camera features, a study has compared the quality of images taken by smartphone cameras and images taken by digital camera and concluded that smartphone cameras have performances similar to the digital cameras and can replace them in image-based teleconsultation [9].

2.5 - Discussion

The areas of eHealth, telemedicine and mHealth have grown a lot in recent years, especially mHealth. The growth of mHealth has been sustained by the fast rhythm at which mobile devices, like sensors, smartphones, smart watches (among others) and internet connection have developed recently and are expected to keep growing in the future. Telemedicine is used nowadays to bring better healthcare in developing regions and to reduce costs and waiting time in developed locations.

Regarding teledentistry, previous studies concluded that its architecture and its working methods were good enough to be valid alternatives to the traditional face to face

consultations. In general, the end users of the study presented in this chapter believed that it would be useful to their jobs, although it could be easier to use.

The different approaches to telemedicine were also presented and discussed. Although they have differences between them, each one of them is suitable for different contexts. It is up to the provider to choose the method that matches the working context, including the patient and their specificities (age, visual acuity and technological ability), the infrastructures available (if there is a good internet network that can handle the communications needed by telemedicine), among other factors.

Chapter 3

Requirements and Use Cases

In this chapter we present the target usage scenarios of the system, considering different user roles and the associated workflows.

3.1 - Opportunities for teledentistry in oral care

This section is about the clinical and the educational uses of teledentistry.

3.1.1 - Medical training

Teledentistry has been used in dental education to deliver alternative ways of teaching [14], like interactive video-conferencing or web-based online courses [18] [32]. Therefore, there is an opportunity to test and document the use of remote assessment of images in dental education.

In the teledentistry system proposed in this work, teachers would take photographs of the volunteers' mouths, then upload them to a server where the students would see and review them. The teacher would then check the reviews made by the students.

The remote assessment of images in dental education would have to be backed up by a system that supports the acquisition of cases and images, their upload to a secure server, an area for students to review the images and another area for teachers to check the reviews made by the students.

3.1.2 - Screening protocols

Screenings are an effective and feasible solution to promote early detection of diseases. An early detection of oral diseases can spare people from pain and expensive treatments [32]. This stands the importance of screenings as a fast and accuracy-cost balanced way to check a part of the population for diseases. If a disease is detected during a screening, the patient can be directed to a specialist for therapeutics and treatments.

Screenings are one of the uses of teledentistry. They were used for screening for new patient orthodontic referrals [33] [34], screening for Early Childhood Caries (ECC) in children at school [26] and preschool [27], caries in patients at a dental clinic [35] [36] and in nursing homes. All of the studies referenced found teledentistry to have at least comparable results to traditional oral examinations and, therefore, considered it to be a good alternative.

A screening made in a childcare center to preschool children [27] is analyzed because it is representative. That screening showed that there were not significant differences between a face-to-face evaluation and a remote evaluation. In that screening, a telehealth assistant took photographs of the children's teeth. Those images were then uploaded to a place where an examiner could access and examine them. A system like this would need to support the acquisition of photographs, their upload to a remote place and a platform for examiners to review the photographs.

3.1.3 - Underserved regions

Teledentistry can also be used to improve the access to oral care for the underserved populations, like for example people living in remote or rural places. Those places are characterized by having difficult or non-existent transportation, lack of general and dental practitioners and poverty [7]. These difficulties lead to a deficiency in health care, which can result in complications for the populations.

It has been found that teledentistry can increase the accessibility of oral care for the underserved populations [32]. That is accomplished by screenings and teleconsultation with dentists. This allows the difficulties that those populations face when dealing with oral care to be mitigated [37].

3.2 - Actors and Use cases of rORAL

Considering the opportunities presented in 3.1 and the fact that image-based diagnosis in teledentistry is feasible, we propose rORAL, a platform to implement remote image-based diagnosis workflows.

There are three types of actors in rORAL. Each type of actor has its own role and set of actions that they can perform (Table 3).

Actors	Description
Operator	Can be a nurse, for example. Their role is to collect info and photographs from the patients, create a clinical case, and submit them for evaluation.
Evaluator	Can be a dentist, for example. Their role is to browse through patients' cases and perform evaluations.
Point of Contact	Can be a teacher, for example. They are responsible for a domain and their role is to create and manage studies and to register evaluators in their domain.

Table 3 - Users of rORAL.

The envisaged solution integrates three different subsystems, each one with its own requirements and use cases:

- 1) rORAL-mob: portable solution, supported in mobile devices, for practical recording of oral care images and insertion of patient data, to be used by Operators.
- 2) rORAL-PoC: web-based portal to create and manage oral health studies and their participants, to be used by Points of Contact
- 3) rORAL-review: web-based portal for experts, allowing to manage worklists and clinical reporting, to be used by Evaluators.

The use cases of each subsystem are described in 3.2.1, 3.2.2 and 3.2.3. A more detailed description of each use case can be found in Annex 1: Use Cases Description.

3.2.1 - rORAL-mob Use Cases

Table 4 explains the use cases supported by the rORAL-mob (Figure 3).

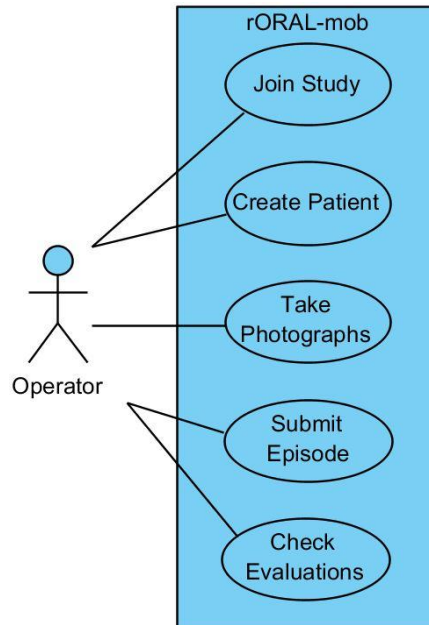


Figure 3 - Use Cases for the rORAL-mob subsystem.

Use Cases	Brief Description
Join Study	The Operator needs to enroll in a study to activate a context for cases to be acquired. The studies are previously created by a Point of Contact. For a secure enrollment, the Operator must present a token, either a provided QR code or password.
Create Patient for a Study	A clinical case is associated to a patient, so the Operator needs to create a patient's record to start collecting cases. To create the patient's record, the Operator needs to give some data about the patient, like name, gender and date of birth.
Take Photographs	A clinical case is made of photographs from a patient. Thus, the Operator needs to use the smartphone's camera to take photographs of the patient for the episodes. The photographs can be transformed to enhance certain parts.
Submit an Episode for evaluation	For an episode to be reviewed by evaluators, it needs to be submitted for evaluation. Therefore, the Operator can submit it from the mobile app and choose normal or high priority. An Episode may also be submitted automatically, if the Operator has set that option in the rORAL-mob settings.
Check an Episode's evaluations	An Operator can check if an Episode has already been evaluated.

Table 4 - Use cases supported by the rORAL-mob.

3.2.2 - rORAL-PoC Use Cases

Table 5 shows a brief description of the use cases supported by the rORAL-PoC (Figure 4).

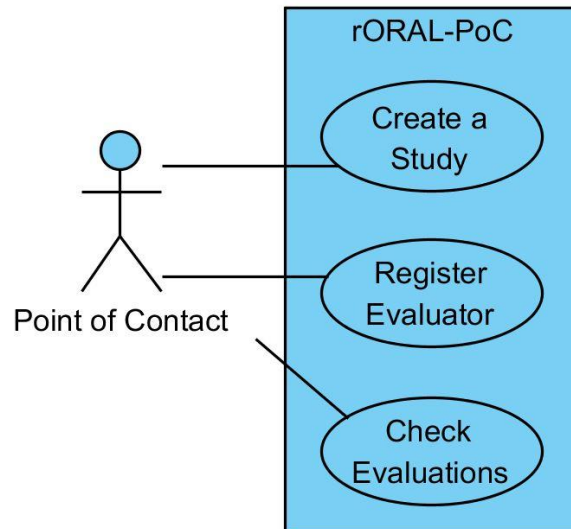


Figure 4 - Use Cases for the rORAL-PoC subsystem.

Use Cases	Brief Description
Create a Study	A study needs to exist for the clinical cases to be collected. A Point of Contact can create a study, after which it is ready to gather patients and their cases.
Register an Evaluator	An Evaluator needs to be registered in a Domain to be able to review the cases from studies in that Domain. A Point of Contact, responsible for the Domain, can register the Evaluator in it, after which they are able to review the cases from the studies.
Check the evaluations	A Point of Contact can check the latest reviews made by their Domain's Evaluators in general, or by a specific Evaluator in their Domain.

Table 5 - Use cases supported by the rORAL-PoC.

3.2.3 - rORAL-review Use Cases

Table 6 depicts the use cases supported by the rORAL-review (Figure 5).

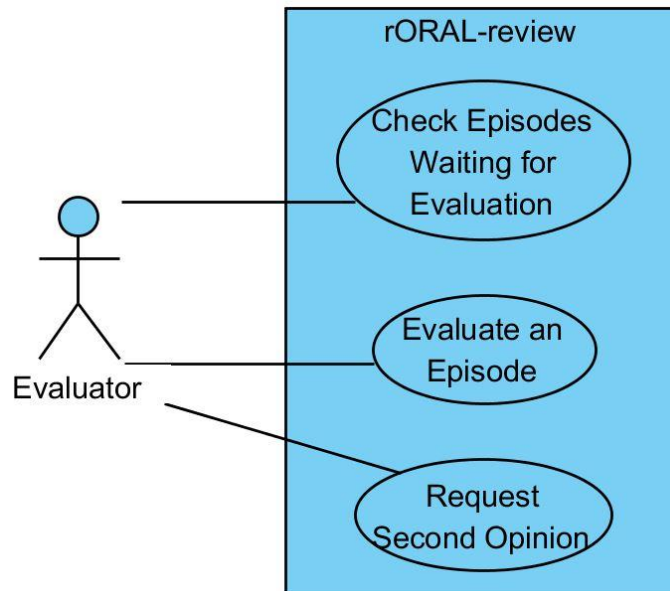


Figure 5 - Use Cases for the rORAL-review subsystem.

Use Cases	Brief Description
Check Episodes waiting for Evaluation	An Evaluator needs to know which Episodes they can evaluate. Therefore, an Evaluator can browse worklists of the Episodes they can evaluate on rORAL-review.
Evaluate an Episode	Reviewing Episodes is the main task of the Evaluators, and they can do it on rORAL-review.
Request Second Opinion	An Evaluator may have doubts regarding an Episode. So, they can ask for other Evaluators to review that Episode.

Table 6 - Use cases supported by the rORAL-review.

3.3 - Sample usage scenario in medical education

A teledentistry platform like the one being proposed can be used to support different application scenarios, such as population screening and medical training. As a proof of concept we chose to support the scenarios implemented at Instituto de Ciências da Saúde in Viseu in their training programme. In those scenarios the students contact with the elderly at nursing homes while they are accompanied and supervised by the teachers.

A possible protocol proposed for the platform is the following (Figure 6):

1. The teacher, registered as Point of Contact, creates a study in rORAL-PoC, preparing it for the students
2. The teacher performs a face-to-face examination at the nursing home to the patients that participate in the study
3. A student, while in physical contact with a patient from the nursing home, performs a face-to-face examination and then logs in rORAL-mob and, as an Operator, registers the patient and takes photographs of their oral cavity, creating a clinical case
4. The student submits the case for evaluation, uploading it to the remote server using rORAL-mob. The case may also be submitted automatically, if the student has set that option in the rORAL-mob settings
5. Another student logs in rORAL-review and, as an Evaluator, browses through the cases needing evaluation and formulates an evaluation for the case
6. The teacher then goes on rORAL-PoC to access the evaluations made by the students and compares them to their face-to-face examination

The step 2 is used for the teacher (or a student under the teacher's supervision) to collect their evaluation of the patients, which they will compare to the student evaluations in step 6. These two steps are used in a medical training scenario but are not necessary in a screening scenario.

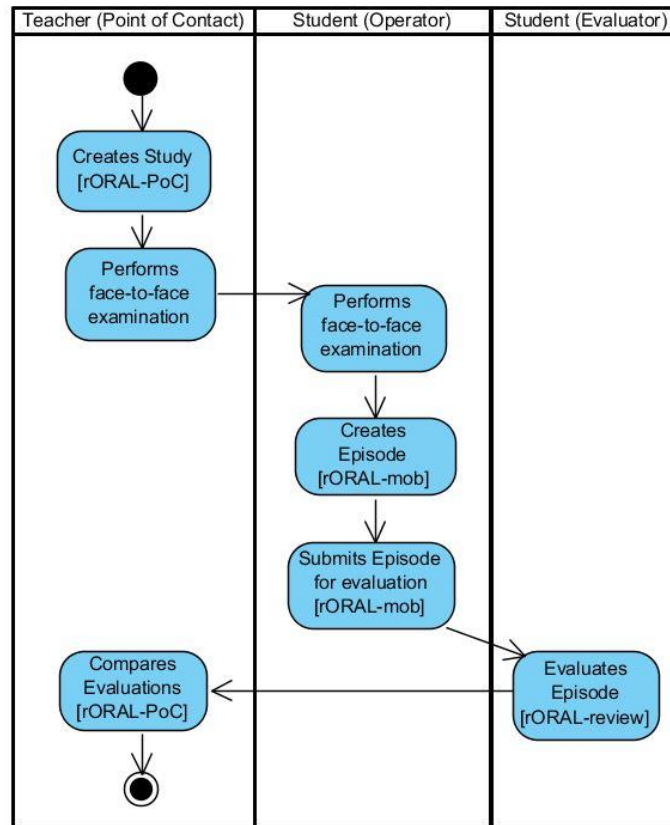


Figure 6 - Activity Diagram for the usage of rORAL in medical education.

3.4 - Discussion

The fields of medical training, screening and granting better oral care to underserved populations provide opportunities for the application of rORAL. Each of these uses has its own specificity and requirements.

rORAL has three types of users: Operators, Evaluators and Points of Contact. They each may be portrayed by people with different occupations, and therefore different roles and tasks within rORAL. The Operator's role is to collect photographs of the patient's oral cavity and submit them for evaluation. The Evaluator's role is to browse through the clinical cases created by the Operators and submit evaluations for them. The Point of Contact's role is to create and manage the studies and the Evaluators within a domain.

Three different categories of use cases of the system were identified: one for the mobile app to be used by Operators, one for the area of the website to be used by Evaluators and another for the area of the website to be used by Points of Contact.

Chapter 4

System Architecture

This chapter presents the concepts involved in the system and the different components that account for the system.

4.1 - Domain Information Model

The system is made of concepts related to each other. Some of them represent people while others represent events or entities. Below there is a description of each one of them, their attributes, and a class diagram representing the relationships between them (Figure 7).

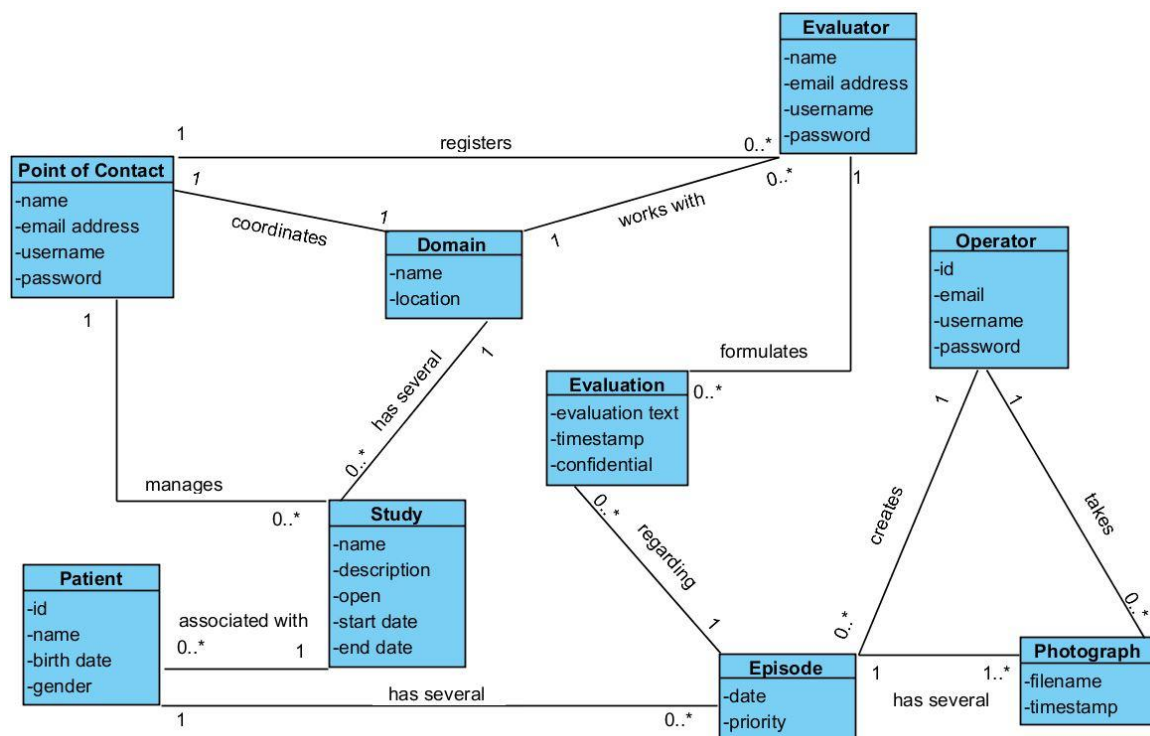


Figure 7 – High-level domain information model.

Domain

A Domain represents an organization context. That organization could be a university, for example. It is the place the Evaluators are affiliated to. The organization has someone in charge, called the Point of Contact, who is responsible for registering Evaluators and creating Studies. The Studies and the entities associated to them (Patients, Episodes, Evaluations and Photographs) exist in the context of a Domain.

The attributes and relationships of the Domain are presented in Table 7.

Attribute	Brief Description
name	the name of this Domain
location	the name of the place where this Domain is
Point of Contact	the Point of Contact in charge for this Domain

Table 7 - Attributes and relationships of the Domain.

Point of Contact

A Point of Contact is a person responsible for a Domain. It can be a teacher, if the Domain is a university, for example. The Point of Contact is responsible for creating Studies and for registering Evaluators in their Domain.

The attributes and relationships of the Point of Contact are shown in Table 8.

Attribute	Brief Description
Domain	the Domain that this Point of Contact is responsible for
name	the name of the person
email address	the email address used by the person
username	the username used to log in the system
password	the password used to log in the system

Table 8 - Attributes and relationships of the Point of Contact.

Study

A Study is associated to a Domain and is created by the Point of Contact of that Domain. The Patients and their Episodes are always associated to a Study and exist in its context. A Study is an aggregation of Patients and Episodes made in a certain place during a certain period of time.

The attributes and relationships of the Study are presented in Table 9.

Attribute	Brief Description
name	the name of the Study
description	the description of the Study
Domain	the Domain in which the Study is

open	to indicate whether the Study is open or closed
start date	the date when the Study was created
end date	the date when the Study was finished

Table 9 - Attributes and relationships of the Study.

Evaluator

The Evaluator is the person who submits Evaluations for the Episodes. Their goal is to make an Evaluation based on the Photographs and other information from the Patient. They can be students in a university or dentists, for example. An Evaluator is always linked to a Domain. This means that they can only review Episodes from that Domain, making the process more easily coordinated by the Domain's Point of Contact.

The attributes and relationships of the Evaluator are shown in Table 10.

Attribute	Brief Description
Domain	the Domain in which they are registered
name	the name of the person
email address	the email address used by the person
username	the username used to log in the system. It identifies an Evaluator unequivocally
password	the password used to log in the system

Table 10 - Attributes and relationships of the Evaluator.

Operator

An Operator is the user of rORAL-mob. They are the only ones in the system that have direct contact with the Patients. They can be, for example, dentistry students. Their responsibility is to provide the data for the Evaluators to review. For that they must enroll in a Study using the credentials given to them by the Point of Contact, create a Patient and insert their personal data (such as name, gender and date of birth), create an Episode for them and then capture the Photographs and submit them for evaluation.

The attributes and relationships of the Operator are shown in Table 11.

Attribute	Brief Description
id	a sequence to identify an operator unequivocally
email	the email address used by the person
username	the username used to log in the system
password	the password used to log in the system

Table 11 - Attributes and relationships of the Operator.

Patient

A Patient is the person whose oral cavity is evaluated. It is usually someone participating in a screening, for example, at a nursing home. Although the person can be discovered from the Patient in the rORAL-mob through their name for example, the same doesn't happen in rORAL-review, where the name isn't displayed to the Evaluators due to privacy policies. The attributes and relationships of the Patient are shown in Table 12.

Attribute	Brief Description
id	used to identify the patient. Each organization should define the semantics for this field. The only requirement to the system is that it is unique inside a Study.
name	the Patient's name
Study	the Study to which this Patient belongs to
birth date	the Patient's date of birth
gender	the Patient's gender

Table 12 - Attributes and relationships of the Patient.

Episode

An Episode is a set of Photographs taken of a Patient in a context. That context can be inferred from its date, the Operator that took them and the Study they belong to. The Episode is the subject of the Evaluations, since the Photographs in it are evaluated as a group, and not individually.

The attributes and relationships of the Episode are shown in Table 13.

Attribute	Brief Description
Patient	the Patient represented in the Episode
Operator	the Operator that created the Episode
Evaluator	the Evaluator responsible for reviewing the Episode
date	the date when the Episode was created
priority	the priority for it to be reviewed. Can be normal or high

Table 13 – Attributes and relationships of the Episode.

Photograph

A Photograph represents the metadata about a photograph taken in an Episode. They are taken by the Operators when they are in contact with the Patients. Then they are uploaded to the server, where the Evaluators can indirectly review them as a set, when they evaluate Episodes.

The attributes and relationships of the Photograph are shown in Table 14.

Attribute	Brief Description
filename	the name of the file where the photograph is stored
timestamp	the date and time when the photograph was taken
Episode	the Episode where this photograph belongs to. The Patient and Operator can be inferred from the Episode.

Table 14 - Attributes and relationships of the Photograph.

Evaluation

An Evaluation is submitted by an Evaluator regarding their review of an Episode. The Operator then receives a notification in the rORAL-mob saying that the Evaluation is ready. The attributes and relationships of the Evaluation are shown in Table 15.

Attribute	Brief Description
Episode	the evaluated Episode
Evaluator	the Evaluator who made the Evaluation
evaluation text	the text submitted with the Evaluation
timestamp	the date when the Evaluation was submitted
confidential	if the evaluation text should be shown to the Operator who created the Episode

Table 15 - Attributes and relationships of the Evaluation.

4.2 - System Components

The system architecture is divided into four main components (Figure 8): Mobile Clinical Cases Acquisition App (rORAL-mob), Studies Management Web App (rORAL-PoC), Review and Evaluation Web App (rORAL-review) and the Backend.

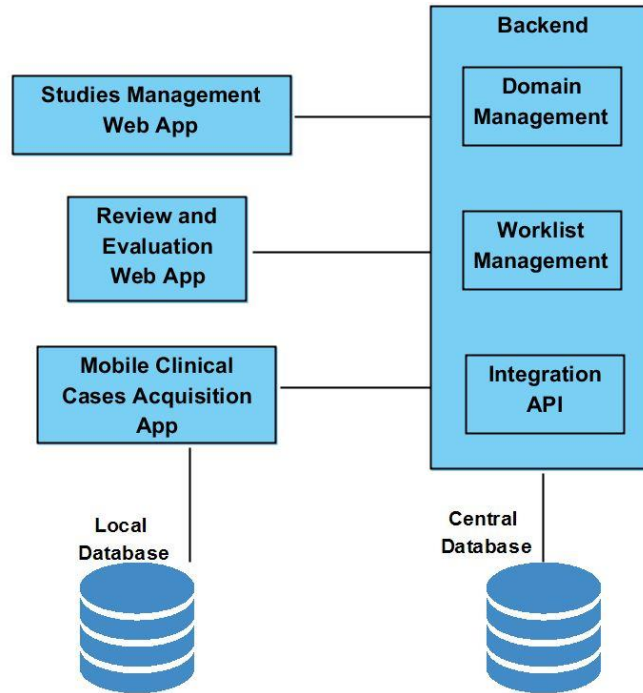


Figure 8 – Proposed architecture for rORAL.

The Mobile Clinical Cases Acquisition is a mobile app to be used by the Operators for capturing oral cavity images and inserting data from the patient. It makes use of a local database to store information about the collected clinical cases. Its main functionalities are to:

- create clinical cases for the patients
- take photographs
- upload records and photographs
- alert the Operator when an Episode is reviewed

Studies Management is a web app to be used by the Points of Contact to create and manage the studies and evaluators registered to their domain. The main functionalities it provides are to:

- register Evaluators in Domains
- check Evaluators' reviews
- create and manage Studies

Review and Evaluation is a web app to be used by the Evaluators to manage worklists and to review clinical cases. The main functionalities it provides are to:

- show Episodes waiting for Evaluation
- allow the Evaluators to review Episodes

Backend is a component that works as the core place for data storage and retrieval in rORAL. It is made up from the Domain Management, the Integration API and the Worklist Management components and uses a database to store and retrieve information. The Studies Management Web App, the Mobile Clinical Cases Acquisition App and the Review and Evaluation Web App communicate with the Backend to synchronize information about studies and clinical cases. The Domain Management component is used by the Studies Management Web App and it provides a logical interface to manage the studies and the evaluators. The Integration API is a REST API that exposes endpoints to be used by the Mobile Clinical Cases Acquisition App. The Worklist Management component provides the Review and Evaluation Web App with the operations necessary to manage the evaluators' worklist and for them to review clinical cases.

4.3 - Data protection

This work involves creating and manipulating patient data and photographs that can reveal sensitive information, requiring that the data is available only for those who truly need it to perform their tasks. Apart from that, nowadays where technology is present in our lives and sensitive data is stored everywhere, certain types of attacks to information are expected to happen. Because of this, it is important not only to keep 'untrusted' people from accessing the data, but also to try to minimize the damages in case someone gets a hold of the data without permission.

Photographs and patient metadata are one of the things that can reveal too much about a person. Because of that they should only be shown when there is at least a relative certainty that the person trying to access them has that permission. The information presented in rORAL-review does not explicitly identify the patient.

Additional details are described in the section Data Security Measures in the Implementation chapter ([5.1.1](#) and [5.2.1](#)).

4.4 - Discussion

The system is composed by four components: rORAL-mob, rORAL-PoC, rORAL-review and backend. The first three are destined for different users, while the backend is the core place for information storage and retrieval, which communicates bidirectionally with the other three mentioned components. rORAL-mob is used by the Operators to create records for their patients, create episodes and take photographs, submit episodes for evaluation

and receive notifications when one of their episodes is evaluated. rORAL-PoC is used by the Points of Contact to register Evaluators, check their reviews and to create and manage studies. rORAL-review is used by the Evaluators to browse episodes pending evaluation and to evaluate those episodes.

Such system, where people get registered and where their photographs get stored, needs to have some security policies to prevent unauthorized people from accessing sensitive data.

Chapter 5

Implementation

5.1 - rORAL-mob

An Android app was developed natively for the mobile clinical cases acquisition subsystem. The following sections (5.1.1 and 5.1.2) address the implementation details and choices and describe the different interactions that the users can have within the app.

5.1.1 - Implementation Details

Evaluating hybrid/native and other Operating Systems

Android is an accessible platform, both in terms of devices and of tools available for developers. As a proof-of-concept it is easier to develop in a platform like Android.

Nonetheless, there are some hybrid tools that allow to develop an app once, in a certain language, and deploy it for several operating systems. Those tools include Xamarin¹⁰, Cordova¹¹, among others. However, there is a catch with code that must be compatible with several different operating systems: it cannot use functionalities exclusive to a certain one of them, or else it would not be compatible with the others.

It was chosen to only develop an Android app (and to do it natively) because it would allow the development to be focused on this platform with no constraints and to avoid the extra effort of making the same app twice, for two different platforms.

Take Photographs

Taking photographs is a big part of this system because Evaluators use the photographs taken by the Operators to assess the Patients. Therefore, the mobile application needed to provide its users a way to take photographs.

¹⁰ <https://www.xamarin.com/>

¹¹ <https://cordova.apache.org/>

This is done using Android Intents¹² and specifying what you want from them. After that, the user picks an app to take a photograph and after they are done with that, the photo gets picked up programmatically and stored in the app's private storage as explained in 4.3 - Data protection.

However, the photos taken were somewhat big (around 1.5 Megabytes). This could make the upload of the photographs take longer. Also, it could spend too much mobile data, which may be a limitation.

One way that we found out to try to fight that was to somehow decrease the size of the photos taken. Therefore, after researching we found out that there was an easy way to compress images in Android¹³. We tested it and reached the conclusion that the images didn't suffer loss of quality (by comparing the same photograph before and after applying the compression) and the compression operation didn't take enough time to hurt the fluidity of the app.

With this solution we managed to reduce the size of the photographs taken from about 1.5 Megabytes to about 300 Kilobytes. With this goal accomplished the Operators can take more photos without reasons to worry about them losing quality or about reaching their mobile data plans limit.

Edit Photos

Operators should be able to edit photos before submitting them for evaluation, for basic preparation of the images, like cropping. In the first stage of trying to fulfill this requirement we searched which image transformations were most commonly used in oral health images. We found a paper that studied the usage of image enhancement in assessing caries in radiographs, which analyzed the transformations of brightness, contrast and gamma in radiographs, therefore we chose to focus on those [38].

After choosing the transformations to work on we started looking for ways to apply them inside the app. We found out that there were libraries available for Android that allowed the developer to apply those on an image.

The first one we used was wasabeef/glide-transformations¹⁴. It had methods for brightness and for contrast. However, it took a lot of time to apply the transformations. When we tested it on a real device it took at least about 3 seconds, sometimes 6 to apply the transformation. As this wasn't very user friendly, and we knew there had to be way for them to be faster, we tried other libraries.

¹² <https://developer.android.com/reference/android/content/Intent.html>

¹³

[https://developer.android.com/reference/android/graphics/Bitmap.html#compress\(android.graphics.Bitmap.CompressFormat, int, java.io.OutputStream\)](https://developer.android.com/reference/android/graphics/Bitmap.html#compress(android.graphics.Bitmap.CompressFormat,int,java.io.OutputStream))

¹⁴ <https://github.com/wasabeef/glide-transformations>

The other one we tried was Zomato/AndroidPhotoFilters¹⁵. This one also had methods to manipulate an image's brightness and contrast. When we tested under the same conditions (the same image and device) in which we tested wasabeef/glide-transformations it only took an average of about 0.3 seconds to apply the transformations and load the images. This is because their code was made in the NDK¹⁶, that allows it to run faster in a layer closer to the hardware.

After having picked the library to use to apply brightness and contrast to the images we still had to pick one to apply gamma. The only library that we found that did that was mukeshsolanki/photofilter¹⁷, but it took more than 10 seconds to apply that transformation on the same image mentioned in the paragraphs above. With that in mind, we decided to remove that filter from the app because it would take much more time than the others.

Apart from the filters mentioned above there was also the possibility to crop images. For that we also searched for libraries that allowed to integrate a cropping component. we tried ArthurHub/Android-Image-Cropper¹⁸ and it fit our needs, so it was integrated in the app.

Show Photos in the app

Showing an image in Android is easy, however some things can go wrong. For example, when we tested the app with many images in the same Activity it got very slow and unresponsive. It even crashed sometimes due to OutOfMemoryError.

To fix that, we followed Android's advice¹⁹ and used Glide²⁰. With Glide, the tasks of image caching, image fetching, image loading in the background, image down sampling and others are automatically done by the library.

One other aspect that could be important to implement was image zooming. Zooming an image greatly helps the user to check if it contains all the details that they wanted to, before submitting the image for evaluation. There are native ways to do so, but the implementation can be quite tricky. So, a quick search was made on faster ways to do that, such as third-party components that allowed to quickly include that functionality in the app.

We found the library chrisbanes/PhotoView²¹, which is very easy to include in the app and even easier to work with. With it all images can be zoomed in and zoomed out smoothly,

¹⁵ <https://github.com/Zomato/AndroidPhotoFilters>

¹⁶ <https://www.zomato.com/blog/our-first-open-source-contribution-stunning-photo-filters-for-your-android-apps>

¹⁷ <https://github.com/mukeshsolanki/photofilter>

¹⁸ <https://github.com/ArthurHub/Android-Image-Cropper>

¹⁹ <https://developer.android.com/topic/performance/graphics/index.html>

²⁰ <https://github.com/bumptech/glide>

²¹ <https://github.com/chrisbanes/PhotoView>

allowing also to zoom into a specific point in the image by double tapping the image in that point.

Representing the models

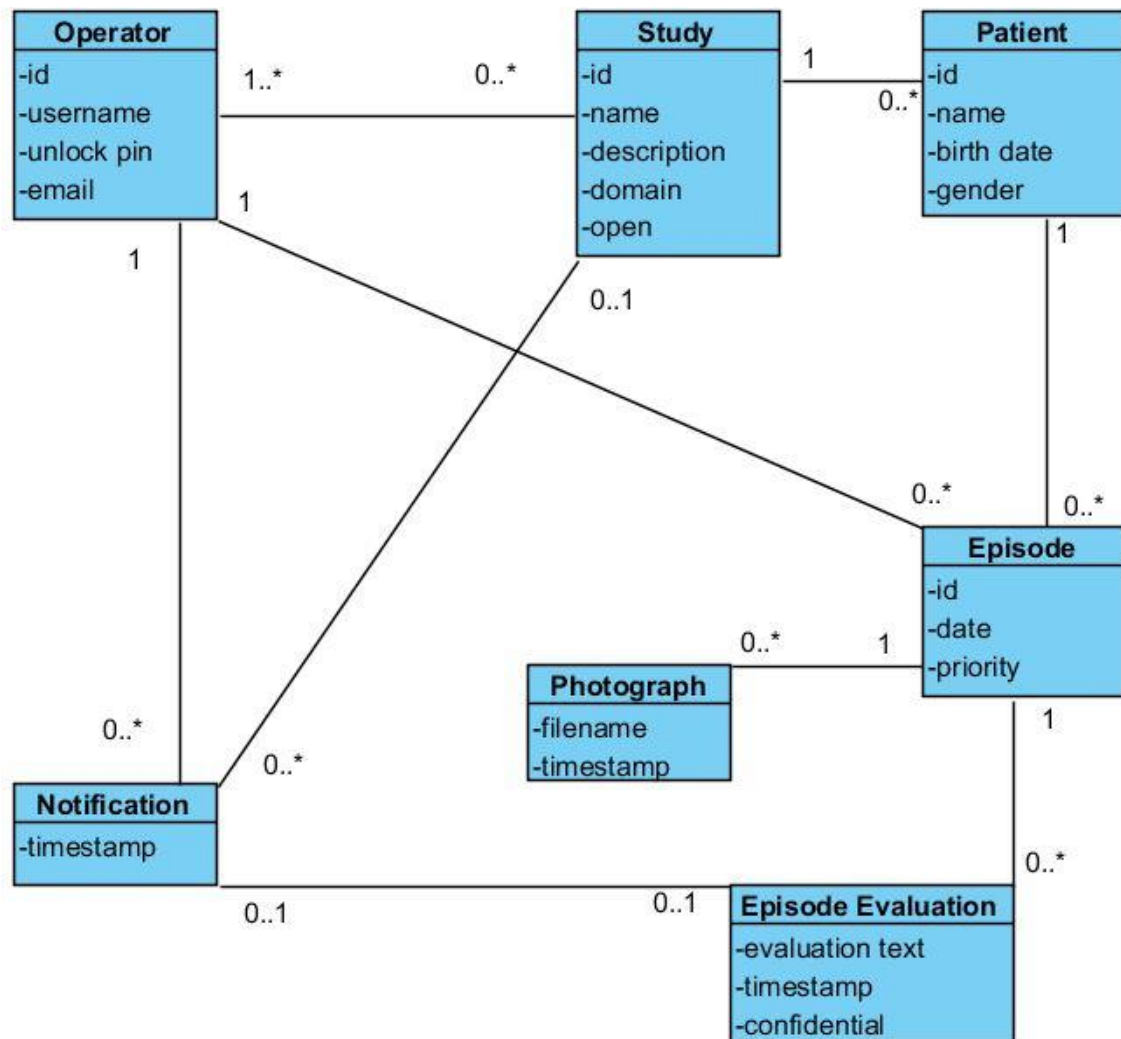


Figure 9 - Class Diagram for the model classes used in rORAL-mob.

The mobile app needs a way to internally represent and persist information entities and the relationships between them (Figure 9).

The most straightforward way to include those models in the app would be creating classes for each of them and using databases for the persistence. The following Java classes were created with this purpose:

- Study

Attribute	Brief Description
id	a sequence to identify the Study unequivocally
name	the name of the Study
description	the description of the Study
domain	the Domain in which the Study is
open	to indicate whether the Study is open or closed

- Operator

Attribute	Brief Description
id	used to identify the Operator unequivocally
username	used for the Operator to log in the app
unlock pin	a sequence of digits to unlock the screen when opening the mobile app. Each Operator has one
email	email address of the Operator

- Patient

Attribute	Brief Description
id	used to identify the patient. Each organization should define the semantics for this field. The only requirement to the system is that it is unique inside a Study.
Study	the Study to which this Patient belongs to
name	the Patient's name
birth date	the Patient's date of birth
gender	the Patient's gender

- Episode

Attribute	Brief Description
id	used to identify the Episode unequivocally
date	the date when the Episode was created
priority	to indicate the priority for it to be reviewed
Patient	the Patient portrayed in the Episode
Operator	the Operator who created the Episode

- Photograph

Attribute	Brief Description
filename	the name of the file where the Photograph is stored
timestamp	the date and time when the Photograph was taken
Episode	the Episode where this Photograph belongs to

- Episode Evaluation

Attribute	Brief Description
Episode	the Episode this Evaluation refers to
evaluation text	the text submitted with the Evaluation, or an empty string if it is confidential
timestamp	the date and time when the Evaluation was submitted
confidential	to indicate whether the Operator should access the text or if they should only know that an Evaluation is ready

- Notification

- This class is exclusive to the mobile app. It is used to represent a notification that was shown to the Operator. The Notification can be about an Episode Evaluation received or about a Study changing from opened to closed, or vice-versa. There is a screen in the app with the sole purpose of showing the Operator all their notifications.

Attribute	Brief Description
timestamp	the date and time when this Notification was received
Operator	the Operator to whom this Notification is shown. For example, if the Notification is for a new Episode Evaluation, then the Operator is the one who created the Episode that got evaluated
Episode Evaluation	the Episode Evaluation referenced by this Notification, or none
Study	the Study referenced by this Notification, or none

After having the classes defined it was time to find a way to apply the persistence. On previous projects we developed on Android we used the core framework to work with SQL queries. However, it demanded a lot of time, patience and trials/errors because we had to write all the raw SQL queries (one for updating, one for deleting, one for inserting, some for searching, etc. All of this times the number of classes present. Plus, the queries weren't verified on compile-time) and the code to convert SQL query results into Java objects. The entire process was too cumbersome, and an abstraction layer over this process would allow great time saving in using persistence in Android. Because of this we used an ORM (Object Relational Mapping) library. These libraries provide an abstraction layer that allows developers to perform CRUD (Create, Read, Update, Delete) operations just by using object oriented programming, with no need to write SQL queries.

After researching the possibilities we had we ended up choosing Sugar ORM (chennaione/sugar²²). Using this library, each entity is represented in a Java class with its name, in which its attributes and methods are defined.

Communication with the remote server

The mobile app needs to exchange data bidirectionally with the backend. One of the data exchanged is the photographs that are sent to the backend. The method we had for sending the photograph over the internet was:

Mobile app:

- Converting the image into a byte array
- Encoding the array of bytes to base 64
- Sending the array of bytes as a parameter in a POST request made to the remote server

Remote server:

- Getting the base 64 array from the request
- Decoding into back into a byte array
- Saving it into a file

However, this method was too cumbersome and error prone, therefore, we started looking for simpler, more robust alternatives.

After looking for better alternatives we found loopj/android-async-http²³. This library, especially made for Android, has the following functionalities:

- asynchronous HTTP requests
- file uploads
- straightforward parameters builder

Looking at the described functionality, where we tried to upload a photograph to the remote server, we were able to do it using this library. It was as easy as adding the photograph file as a parameter to the POST request. This library is used for all the HTTP requests made in the app, namely with the Integration API.

In some of the transactions between the app and the backend there is an exchange of Java objects. For example, when the app asks the remote server about an Episode's Evaluations the remote server answers back with a JSON array of all the Evaluations of that Episode (Figure 10). As JSON was the format chosen to send those objects over HTTP requests we found a simple way to serialize and deserialize them into/from JSON. Using google/gson²⁴ it becomes as simple as writing one line of code.

²² <https://github.com/chennaione/sugar>

²³ <https://github.com/loopj/android-async-http>

²⁴ <https://github.com/google/gson>

```

{
  "episodeID": "1510405029981",
  "evaluation": "carie",
  "timestamp": "2017-11-14 20:04:15",
  "confidential": false
},
{
  "episodeID": "1510405029981",
  "evaluation": "PUNA",
  "timestamp": "2017-11-14 20:03:09",
  "confidential": false
},
{
  "episodeID": "1510405029981",
  "evaluation": "",
  "timestamp": "2017-11-14 20:02:51",
  "confidential": true
}

```

Figure 10 - Excerpt of a JSON response sent by the Integration API.

Data Security Measures

PINs and QR codes

When the user closes the mobile app and opens it again they must write the PIN (Figure 11) defined by them upon logging in the app for the first time on that device. The user can change the PIN anytime they decide to. If they forget the PIN they can reset it but then they must log out and log in again before defining a new PIN, to verify again the identity of the user.

Figure 11 - PIN screen in rORAL-mob.

An ID and PIN combination or a QR code (Figure 12) is also necessary for the Operators to join Studies. It is up to the Points of Contact to send those credentials to the relevant Operators.



Figure 12 - Example of a QR code used to join a Study in rORAL-mob.

Photos and Patient data only accessible inside the app

The devices in which rORAL-mob is installed are likely to have many apps installed, and be used by more than one person. Most devices have a gallery, where the photographs taken by the user end up in. However, the photographs taken by the user within rORAL-mob cannot end up in a public place, where anyone with access to the device can see them. To prevent that, the photographs are stored only in a private place specific for rORAL-mob, meaning that the other apps cannot access them and that the users of the device can only access them from within the app. The patients' data is stored inside a private database which can only be accessed by this app, so it is hidden from all the other apps and users.

5.1.2 - Supported Interactions

In this section the different interactions supported in rORAL-mob are explained and a guide is presented for each of them. Although there are two languages for the app (Portuguese and English) only the Portuguese version is shown.

Join a Study

An Operator needs to enroll in a study, previously created by a Point of Contact, to have a context in which clinical cases are made. To perform this action the Operator must be logged in rORAL-mob and the device needs to be connected to the internet. This feature is accessible in the screen shown right after a successful login. Then the Operator clicks the 'Adira a Outro Estudo' button and then, for a secure enrollment, they need to insert the necessary credentials, which are either a combination of an ID and a PIN or a QR code. The credentials are sent to the backend on a HTTP request for validation, after which, if the credentials are validated, the Operator is enrolled in the Study and can use it as context (Figure 13).

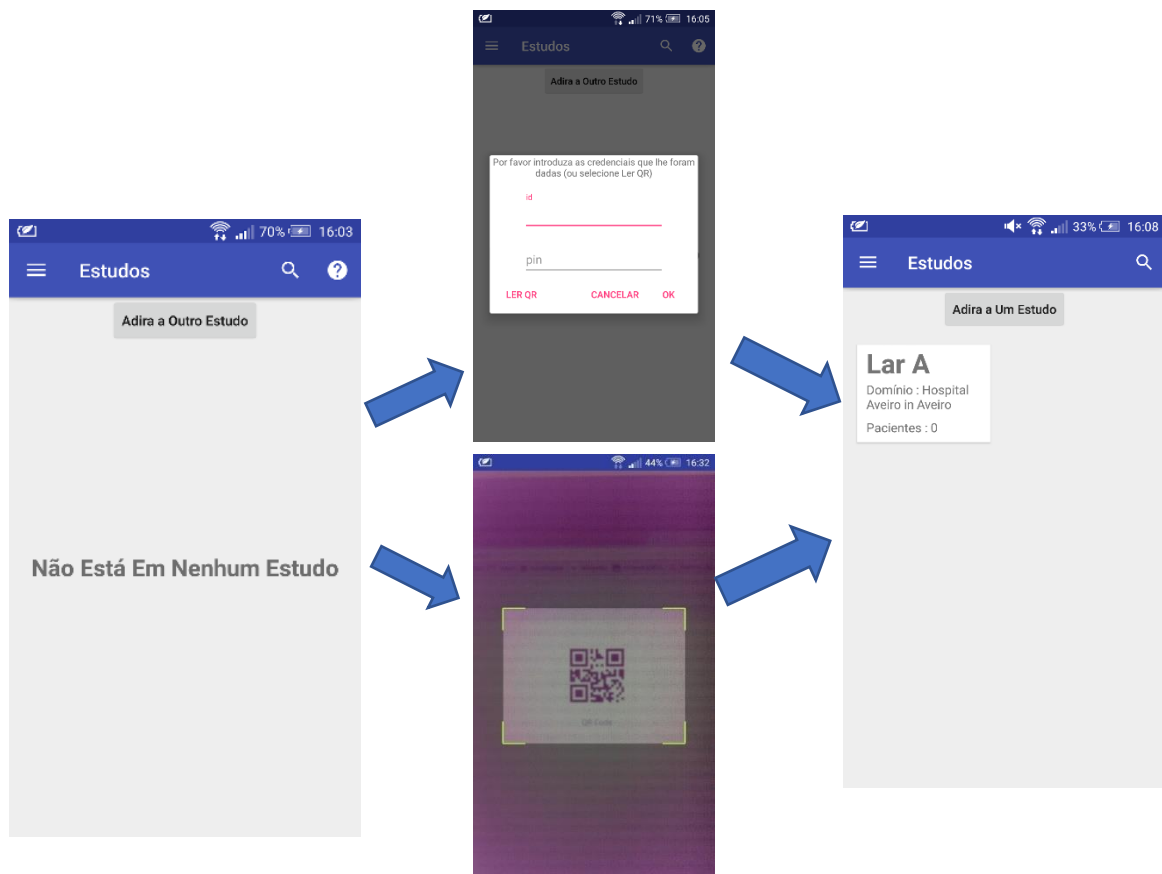


Figure 13 - Overview of joining a Study in rORAL-mob.

Create Patients for a Study

A clinical case is associated to a patient, so the Operator needs to create a patient's record to start collecting their cases. To perform this action the Operator must be logged in rORAL-mob and enrolled in a Study. This feature is accessible in the screen that presents a Study's information, which is shown after they select a Study in the home screen. In that screen the Operator clicks the 'Adicionar Paciente' button and then they need to fill some data required about the patient, like name, ID, gender and date of birth. After rORAL-mob checks the data inserted and, if all fields have valid data like a non-empty name and a birth date before the current date, the Patient is created and is ready for Episodes to be captured (Figure 14).

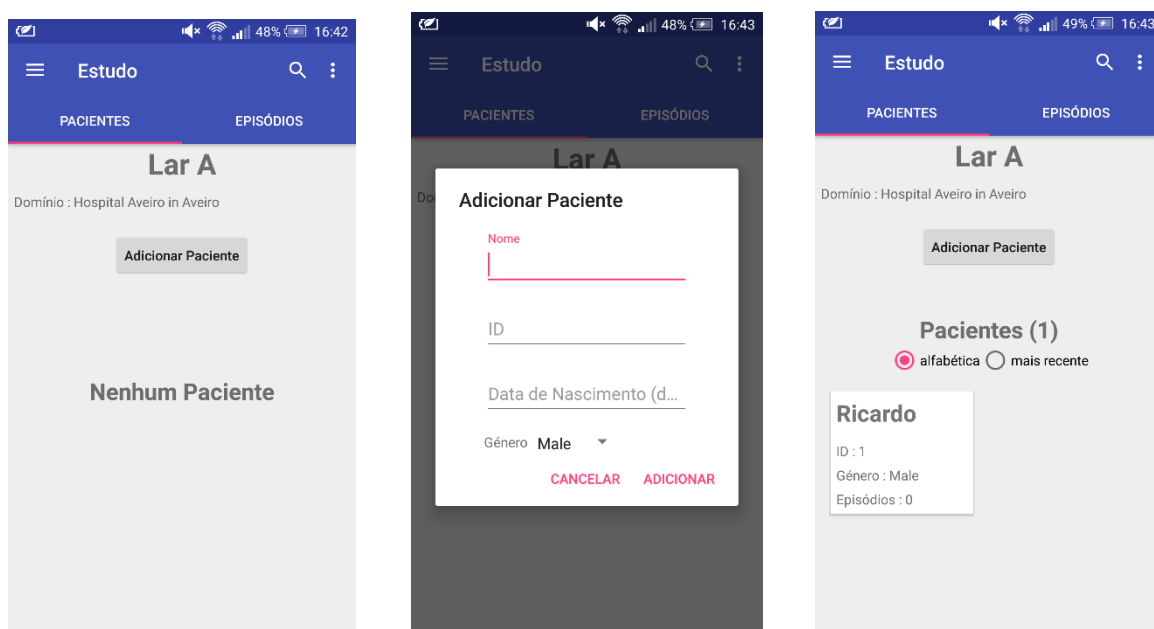


Figure 14 - Overview of creating Patients for a Study in rORAL-mob.

Take Photographs of a Patient

A clinical case (Episode) is made of Photographs from a Patient. The Operator needs to use the device's camera to take Photographs of the Patient for the clinical cases. Before doing this, the Operator must be logged in rORAL-mob, enrolled in a Study and have created a Patient. To access this feature the Operator must select a Study in the home screen and then select a Patient. Then the Operator clicks the 'Novo Episódio' button and is taken to the Episode detail screen. There, the Operator clicks the camera Floating Action Button and takes a Photograph. After the Operator is done taking Photographs they can click the 'Interromper Episódio' option in the toolbar, stopping the capture of Photographs for the Episode (Figure 15). In the last image of Figure 15 the red square in the Episode card means that it has not been reviewed yet (it turns green when there are reviews) and the cloud symbol cut by a line means that the Episode has not been submitted yet (the line disappears once the Episode gets submitted). The Episode can be resumed later, as long as it has not been submitted yet. The Photographs taken in the Episode can be manually enhanced, like cropped and their brightness and contrast can be manipulated (Figure 16).

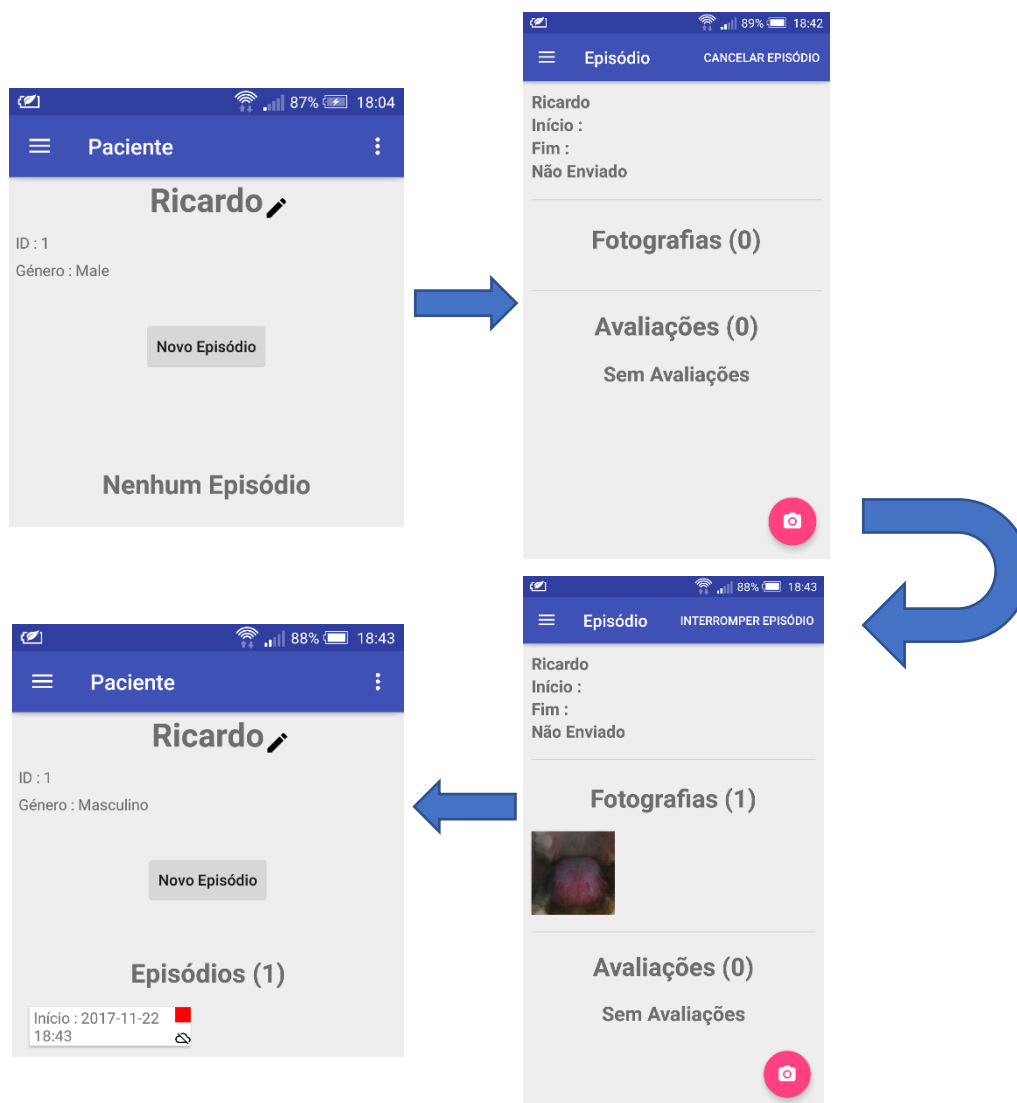


Figure 15 - Overview of creating an Episode in rORAL-mob.

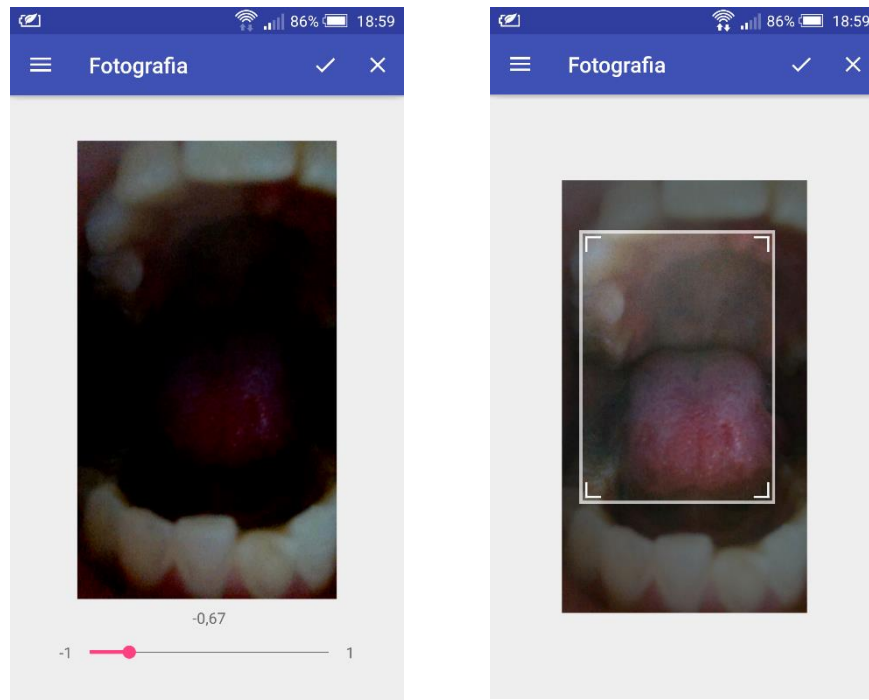


Figure 16 - Cropping and changing a Photograph's brightness in rORAL-mob.

Submit an Episode for Evaluation

For an Episode to be reviewed by the Evaluators, it needs to be submitted for evaluation. The Operator can submit it from rORAL-mob. Before doing this, the Operator must be logged in rORAL-mob and have an Episode ready for submission and the device must be connected to the internet. This feature is accessible in the screen that presents an Episode's information, which is shown once the Operator selects a Study in the home screen and a Patient in the following screen. Then the Operator selects the Upload option in the toolbar, represented by a cloud. Here they are shown a dialog asking if they want the Episode to have normal or high priority. This attribute will be seen by the Evaluators when building their worklist. After choosing the priority, rORAL-mob sends an HTTP POST request to the backend with the Photographs and info regarding the Patient and Episode. Upon successful submission, the Episode awaits reviewing in rORAL-review and rORAL-mob signals the Episode as submitted, notifying the Operator. In the last image in Figure 17 a cloud symbol is shown in the Episode's card, meaning that it has been submitted. From then on, rORAL-mob alerts the Operator whenever the Episode is reviewed (Figure 17).

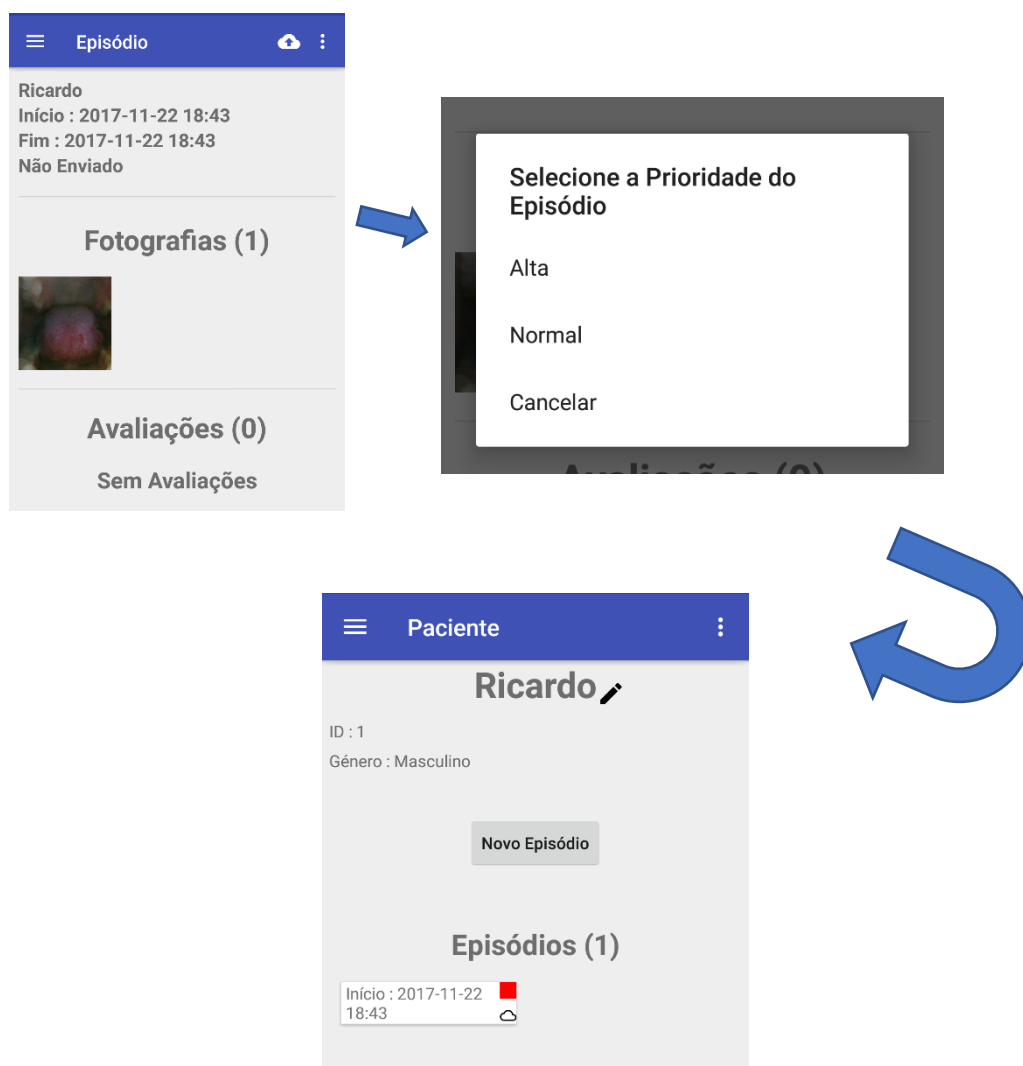


Figure 17 - Overview of submitting an Episode for evaluation in rORAL-mob.

Check an Episode's Evaluations

An Operator receives a notification in rORAL-mob whenever one of their Episodes gets reviewed. Nonetheless, they can access a submitted Episode in rORAL-mob, and, if there is an internet connection, rORAL-mob automatically issues an HTTP GET request to the backend, fetching that Episode's Evaluations and displaying them to the Operator. The green square in the Episode's card means that it has been reviewed (Figure 18).

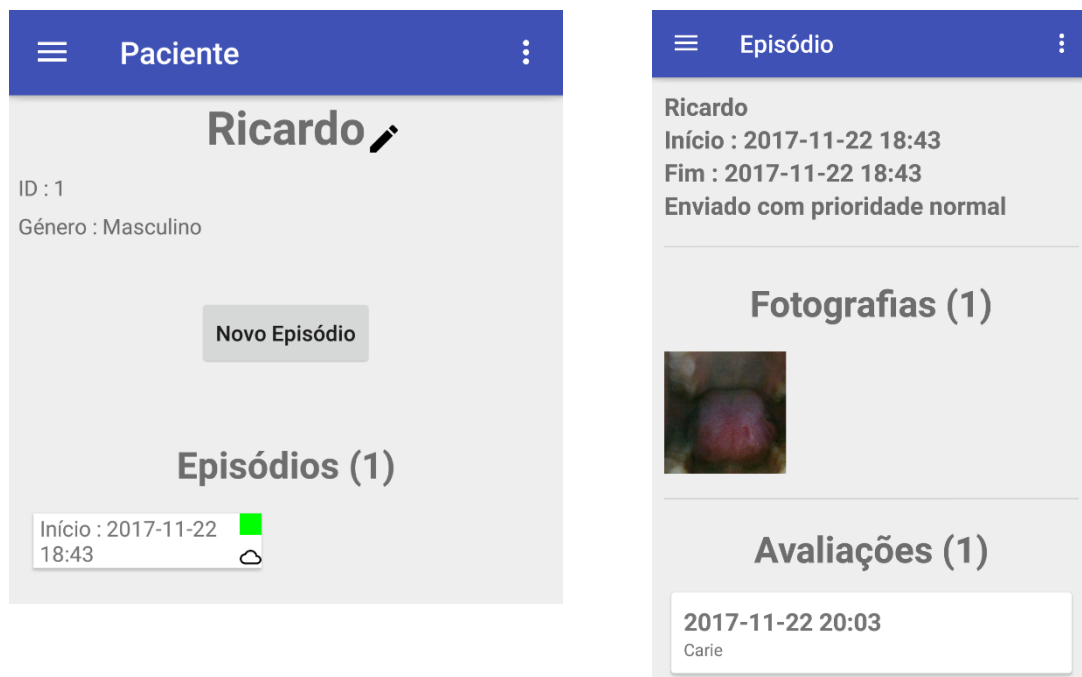


Figure 18 - Overview of checking an Episode's Evaluations in rORAL-mob.

5.2 - *rORAL-PoC, rORAL-review and backend*

rORAL-PoC, rORAL-review and the backend were developed and deployed into a remote server. The studies management, review and evaluation, integration API and file storage components were implemented in it. The following sections (5.2.1 and 5.2.2) describe the implementation details and choices and the different interactions that the users can have within the website.

5.2.1 - Implementation Details

Selection of the Web Development Framework

The backend was implemented using the Django²⁵ framework. Django is a server-side web framework (one of the most popular) written in Python and is used for a faster and easier development of web applications. It promotes the reusability of components and the “Don’t Repeat Yourself” principle, for the developer to avoid wasting time writing code that has already been written before. It comes with many modules that easily allow the programmer to implement authentication, form rendering and processing and also mechanisms against some common web attacks like cross-site scripting (XSS) and SQL injection, for example.

Django uses a Model-View-Controller architecture, composed of an object-relational mapper that makes a correspondence between data models defined in Python and tables in a relational database, a component for handling HTTP requests and presenting webpages using a web templating system and a URL dispatcher that matches URLs with functions defined in the code, which are executed to generate webpages and present them to the user. Django allows the programmer to manipulate data in databases by using Python objects instead of writing SQL queries by exposing an API for CRUD operations. This allows the programmer to greatly reduce the time spent in writing and testing SQL queries, as well as reducing the increased risk inherent to writing hundreds of SQL queries. Django also has a library for handling web forms. This library handles the HTML rendering of the forms, validating data submitted in them and then converting the data into variables that Python understands. All the programmer does is creating a subclass of that library and defining its attributes.

For the reasons stated above, Django was chosen for the development of the backend, allowing a more structured and quicker development.

²⁵ <https://www.djangoproject.com/>

Deployment

The backend must always be available. This is due to it being the core storage place and data repository for the system. In fact, transposing this into a client-server model, the backend is the server and rORAL-mob is the client. Therefore, it needs to be immortal (meaning that it must have a high availability) and known (meaning that its address must be always known to the clients).

So, the remote server had to be deployed into a reliable place, preferably with a URL for the clients.

Heroku²⁶, which is a cloud-based platform-as-a-service, was chosen due to being one of the most popular options for hosting of Django projects. Regarding its functionalities, some of the most useful are that it allows for the automatic deploy of code when the programmer performs a push request into a remote GitHub²⁷ repository, and the use of relational databases easily accessible programmatically. Plus, it allows for free accounts, although they have some limits, like the number of rows in the database.

Storage of Photographs

Photographs are nuclear for the well-functioning of the system, as they are the primary data that the Evaluators will check when assessing the clinical cases. Therefore, the photographs need to be persisted in a reliable place as soon as they are uploaded from the mobile app.

The free account used in Heroku only allows for temporary storage of pictures. For that reason, we turned to Dropbox and chose it as the storage place for the photographs. Dropbox²⁸ has a Python SDK which provides functionalities such as file upload and retrieving a URL for a file stored in a Dropbox account. These two functionalities are the main ones required by the backend. A free Dropbox account was made for the platform. An image is uploaded to the Dropbox account every time a Photograph is uploaded to the backend. When an image is to be displayed in the website, a URL of that image is retrieved from Dropbox and used to display it.

²⁶ <https://www.heroku.com/>

²⁷ <https://github.com/>

²⁸ <https://www.dropbox.com/>

Development of the Integration API

The integration API is the system's component responsible for handling the requests made by rORAL-mob. These requests range from checking users' credentials for login, registering users in the backend, checking if the PIN entered for enrolling in a study is correct, uploading patients records and photographs and checking if there are evaluations ready for a specific episode.

There is a very popular third-party library for Django, called Django REST Framework²⁹ (DRF). It can be integrated into a Django project with just one line of code, following Django's pluggability of components philosophy. This library makes it easier to develop web APIs, with out-of-the-box authentication and authorization, serialization of model objects, easy handling of request parameters and a great and very readable documentation.

DRF provides some easy to use authentication implementations. In this work, the token authentication was used to provide some level of security. It consists in every Operator having an alphanumeric token, which is included in the HTTP authorization headers of every request they make to the API. If no token is provided, or if it doesn't match any user, the request is denied.

Sending messages to the Operators

It is the rORAL-mob who starts most of the communications, sending requests to the backend. However, there is also the need for the backend to send messages to operators. This need arises from the necessity of the backend to communicate to an operator when an evaluation is ready for one of the episodes they have submitted or to communicate to all operators enrolled in a specific study when that study either closes or reopens.

To provide this functionality Firebase Cloud Messaging³⁰ (FCM) was used. It is one service of the Firebase bundle, which is a backend as a service used for mobile and web application development. FCM can be used to send messages and notifications to mobile (Android and iOS) and to web clients. Those can be sent either to a specific device, groups of devices or to topics, which are message channels that clients can subscribe.

The documented way of sending messages through FCM was to send HTTP POST requests to the FCM endpoint. That request would be authenticated with the project created in the Firebase console and the specificities of the message (Destination, the text in the message, etc.) were present in the parameters of the request. This approach was cumbersome as it did not allow to treat messages as objects and then call a method on them to send the messages.

²⁹ <http://www.django-rest-framework.org/>

³⁰ <https://firebase.google.com/products/cloud-messaging/>

However, olucurious/PyFCM³¹, a library developed in Python, was found and provided an abstraction layer over the creation of the HTTP requests and added a class with methods to build and send the messages. That allowed to remove the burden of having to code all the HTTP requests for sending messages to users.

Data Security Measures

Passwords not stored in clear text

The passwords used to log into accounts are stored in the database (only in the backend, not in the smartphone). They are not stored in clear text. Instead, a hash of the password is stored, and whenever there is a log in attempt, the sequence inserted in the login form is hashed and compared with the hash stored in the database.

A person cannot be identified by Evaluators

The Patient entity has some attributes that allow to identify a person. For example, an Operator can easily identify a person by the name that appears in rORAL-mob. However, an Evaluator should not be able to do that. So, to enforce this measure, the names of the Patients and other personal identifiers (unique) aren't stored in the backend, nor shown to the Evaluators. What is stored is a unique key that each Domain, represented by a Point of Contact, should define the semantics for. By doing this, the data is stored in a pseudonymized way.

³¹ <https://github.com/olucurious/PyFCM>

5.2.2 - Supported Interactions

In this section the different interactions supported by rORAL-PoC and rORAL-review are explained and a guide is presented for each of them.

Create a Study

A Study needs to exist for clinical cases to be collected, and it's the Point of Contact's task to create Studies, which they can do in rORAL-PoC. First, the point of Contact needs to be logged in rORAL-PoC. Then, they go to the Studies page and click the 'Create Study' button, which displays a dialog prompting for details of the Study, like its name, description and the PIN that will be used by Operators to join it. Upon confirming the data inserted, and if rORAL-PoC validates it, the Study gets created and is ready to be a context for Patients and their Episodes (Figure 19).



Add Study ×

Name:

Description:

PIN Code:

Create



Display List Grid No Work Available Work Available

Lar A

Description : Captura no Lar A

Domain : Hospital Aveiro in Aveiro

Start Date : 23 November 2017 15:07

Active : ✓

Figure 19 - Overview of creating a Study in rORAL-PoC.

Register an Evaluator

An Evaluator needs to be registered in a Domain to be able to review the cases for studies in that Domain. A Point of Contact responsible for the Domain can register the Evaluator in it, after which they are able to review its Studies' clinical cases. First, the Point of Contact needs to be logged in rORAL-PoC. Then, they go to the Evaluators page and click the 'Add Evaluator' button, which displays a dialog prompting for the Evaluator's email address, in which they will receive a link to a page where they can complete their registration. After that, the Evaluator can start reviewing Episodes (Figure 20).

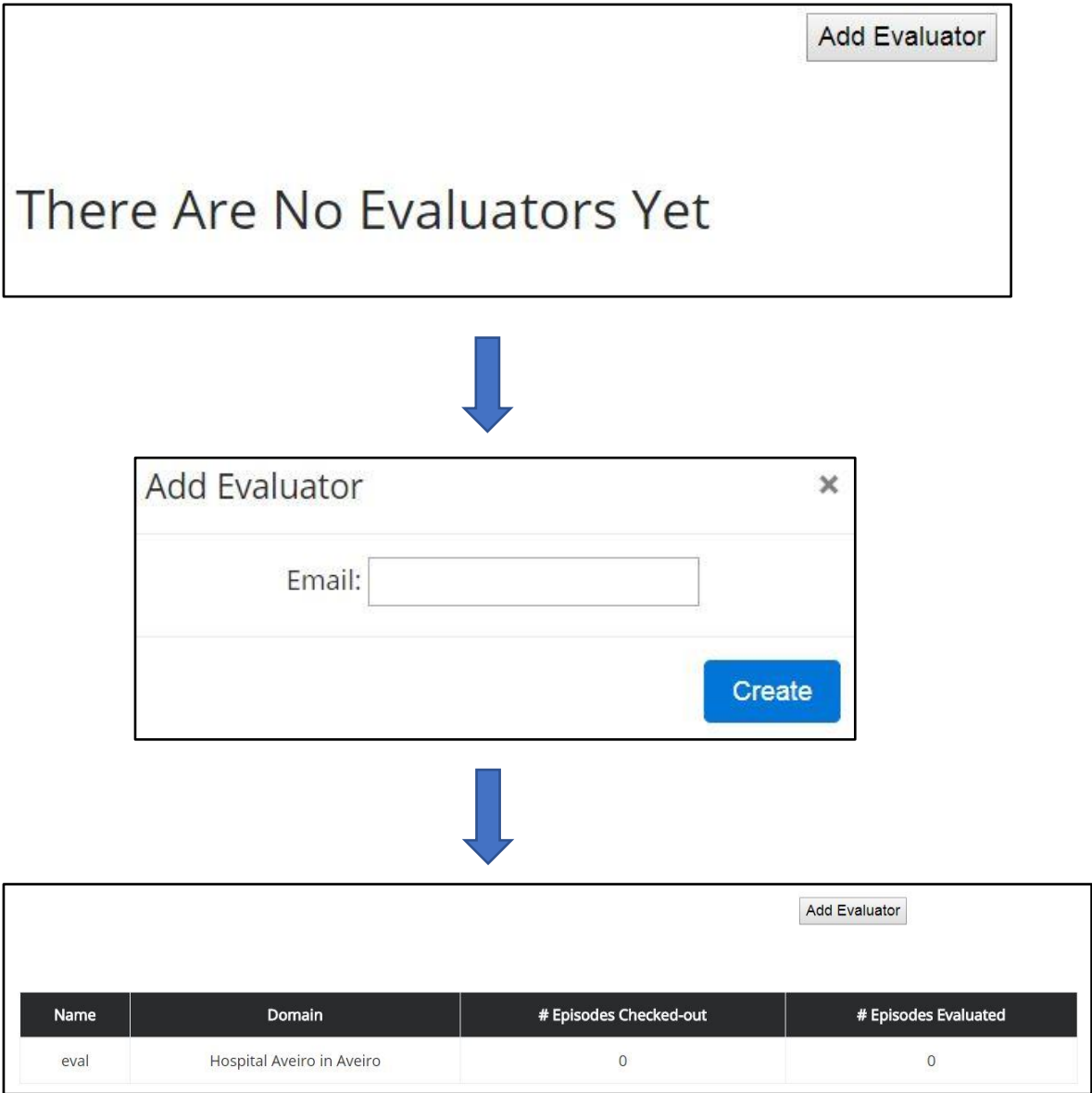


Figure 20 - Overview of registering an Evaluator in rORAL-PoC.

Check the work done by the Evaluators

A Point of Contact can check an ordered list with the latest work done by the Evaluators registered in their own Domain. First, the Point of Contact needs to be logged in rORAL-PoC. Then, in the homepage, they are shown an ordered list with the latest reviews made by the Evaluators. If the Point of Contact selects a review they are taken to the correspondent Episode's page, where the review and its date and author are displayed. If the Point of Contact wants to see the reviews made by a specific Evaluator they can go to the Evaluators page and select one Evaluator from the list. Then, they are shown a list of the Episodes that the Evaluator have checked out and whether they have evaluated them. In this page the Point of Contact can also select an Episode and then they are taken to that Episode's page, where they can see the reviews made for it (Figure 21).

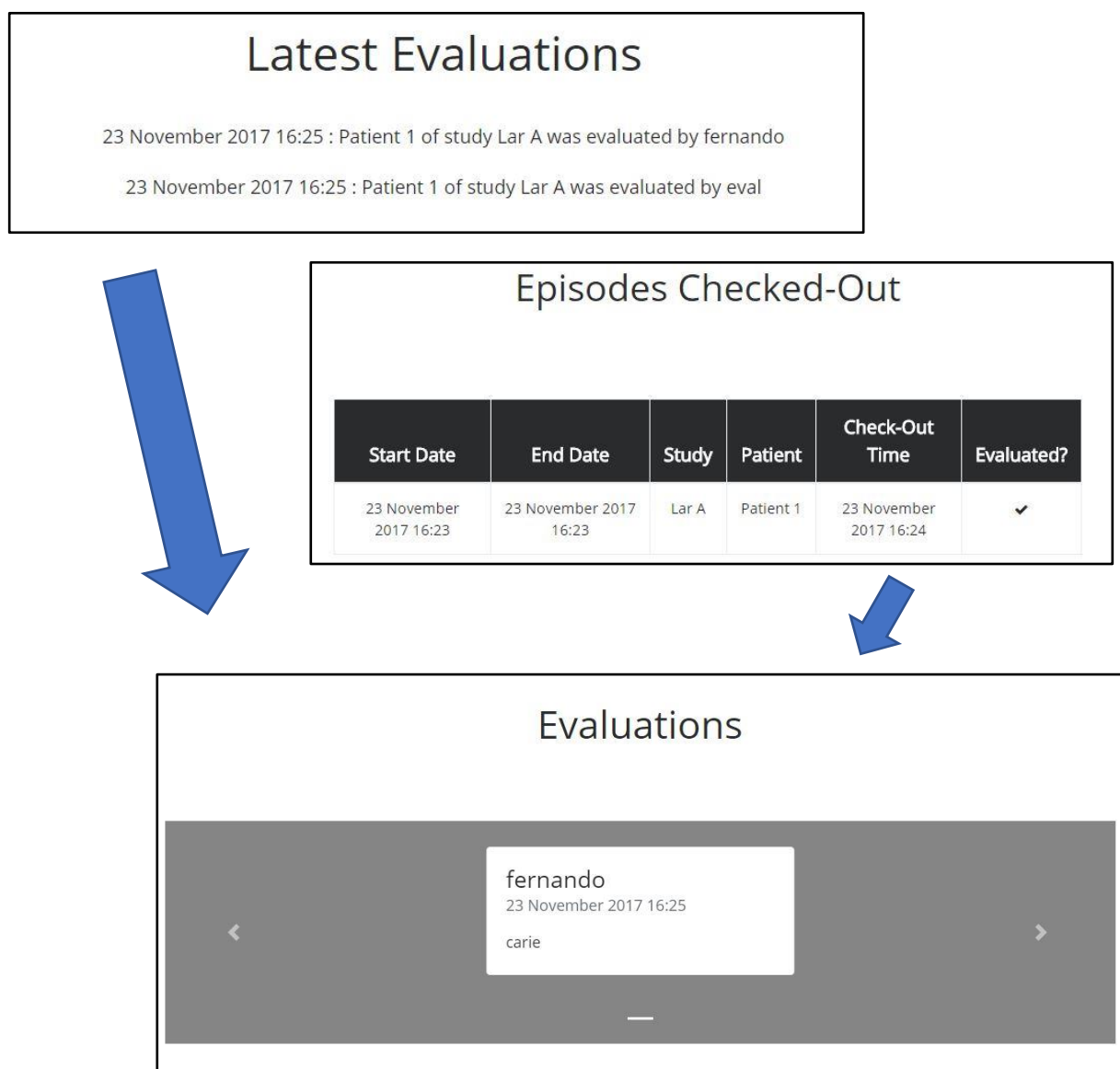








Figure 21 - Overview of checking the latest evaluations made on rORAL-PoC.


See the list of Episodes waiting for Evaluation

An Evaluator needs to know which episodes they can evaluate. Therefore, an Evaluator can browse worklists of the Episodes they can evaluate on rORAL-review. To do this, the Evaluator must be logged in. Then, they go to the Episodes Waiting for Checkout page, which shows all the episodes that this Evaluator can check out. The episodes are assigned a different color according to their priority, which was set by the Operator who created them. From this page the Evaluator can select one episode, perform a checkout to assign it to their worklist and evaluate it (Figure 22).

Display  List  Grid

Sort by  Date  Patient  Priority

 Normal Priority

 High Priority

Study : Lar A

Patient : 1

Date : 22 November 2017

Photos : 1

Study : Lar A

Patient : 1

Date : 23 November 2017

Photos : 1

Figure 22 - Page in rORAL-review showing the episodes waiting for checkout.

Evaluate an Episode

The main task for Evaluators in rORAL is to review Episodes, which they can review in rORAL-review. First, the Evaluator must be logged in. Then, they go to the Episodes Waiting For Checkout page, where they can see a list of all the Episodes that haven't been assigned to an Operator yet (Figure 22). There, the Operator selects an Episode and clicks the 'Checkout' button, which adds the Episode to their worklist and prevents other Evaluators from accessing it. The next step is for the Evaluator to fill the evaluation form with their review and click the 'Submit Evaluation' button, which submits the evaluation and notifies the Operator who created the Episode. If the 'Show the Operator' checkbox is selected the Operator doesn't receive the text submitted with the evaluation, receives only an alert that someone submitted a review for their Episode. If the checkbox is not selected, the text is sent to the Operator (Figure 23).

The diagram illustrates the process of evaluating an episode in rORAL-review. It consists of two main parts connected by a blue arrow pointing downwards.

The top part is a card representing an episode. It features a grey silhouette of a person on the left, labeled "Patient 1". To the right of the silhouette, the text reads: "Study - Lar A in Hospital Aveiro in Aveiro", "Patient - 1", "Patient's Gender : Male", "Patient's Date of Birth : 16 December 1993 (23 yo)", "Episode captured on - 23 November 2017", and "Hasn't been checked-out". At the bottom right of this card is a button labeled "Checkout".

A blue arrow points from the "Checkout" button to the bottom part of the diagram, which is a card titled "Evaluate".

The "Evaluate" card contains a large text area for writing the evaluation. The word "Carie" is written in the top left corner of this area. Below the text area is a checkbox labeled "Show the Operator:" which is checked. At the bottom right of the card is a button labeled "Submit Evaluation".

Figure 23 - Overview of evaluating an Episode in rORAL-review.

Request Second Opinion regarding an Episode

An Evaluator may have doubts regarding an Episode. So, they can ask for other Evaluators to review that Episode. They can request a second opinion on the Episode whether they have evaluated it already or not. To do that, the Evaluator must be logged in on rORAL-review and have checked out an Episode. Then, they go to that Episode's page (from the Checked Out Episodes page if they have not evaluated it or from the Evaluated Episodes page if they have) and click the 'Request Second Opinion' button, which signals the Episode as available for checkout by a second Operator, making it appear in other Evaluators' Episodes Waiting For Checkout page. From that point onwards, any other Evaluator can checkout that Episode and evaluate it. Once another Evaluator reviews the Episode, the original Evaluator will be notified by email and it will appear on their homepage in rORAL-review (Figure 24).



Figure 24 - Overview of requesting a second opinion on rORAL-review.

Chapter 6

rORAL Evaluation

To validate the system, a pilot study was performed, followed by a questionnaire to the users. Both are described in this chapter. The pilot study was approved by the Ethical Committee of the University of Aveiro.

6.1 - Pilot Study

rORAL was evaluated by assessing the accordance between diagnosis performed by dentists, through direct examination, and diagnosis performed remotely by dentists, through the rORAL-review.

This pilot study was performed in a teaching environment. The users of the test were students of the Integrated Master in Dental Medicine at the Health Sciences Institute of the Portuguese Catholic University (ICS-Viseu), in the context of the subject of gerodontology, under the supervision of Professor Nélío Jorge Veiga.

The participation in the pilot was voluntary. All the participants signed an informed consent, and their participation did not bring and will not bring any risk or do any harm to their physical and moral integrity. The data collected during the study was pseudonymized.

The protocol of the pilot was the following. After registering the patient in the rORAL-mob, the dental assistants created clinical cases and collected several photographs of the oral cavity of the patient, paying special attention to areas with diseases and/or special conditions. Those cases were then uploaded to the remote server for later evaluation through the rORAL-review. Nineteen patients, predominantly females (11), presenting oral diseases were enrolled in this study, with ages ranging from 5 to 89 years old (50 ± 23). Afterwards, the dentist performed a direct examination and reported the respective diagnosis, which was considered as gold standard.

Through the rORAL-review, the uploaded cases were evaluated by 2 dentist evaluators (with large experience in clinical practice), performing 2 independent diagnoses for each clinical case.

Although both the students and the dentist evaluators reviewed the cases, only the assessment made by the dentist evaluators was considered to measure the reliability of rORAL.

The diagnoses made during the clinical oral examination and the comparison with the diagnoses of each of the evaluators are presented in Table 16. The first column states the patient, the second column states the diagnosis made by the dentist when they assessed the patients face-to-face at the clinic and the third and fourth columns state the diagnosis made by dentist evaluator 1 and 2, respectively, that only assessed the patient by looking at their clinical case in rORAL-review. Each cell in columns 3 and 4 is colored either in green, if the diagnosis matches the direct examination, or in yellow, if the diagnosis does not match the direct examination.

PATIENT #	FACE-TO-FACE EVALUATION	REMOTE EVALUATION 1	REMOTE EVALUATION 2
1	Gingivitis	different	different
2	NUP	match	match
3	Periodontal disease	match	match
4	Cervical carie	match	different
5	Leukoplakia	match	match
6	Radicular carier	match	different
7	Dental erosion	match	match
8	Fistula	match	match
9	Carie	different	different
10	Carie	match	match
11	Carie	match	match
12	Gingival hyperplasia	match	different
13	Carie	match	match
14	Carie	match	match
15	Carie	match	match
16	Tartar	match	match
17	Carie	match	match
18	Carie	match	match
19	Carie	match	match

Table 16 - Results of the assessments made in the pilot use of rORAL.

From Table 16 it is possible to observe that, out of 19 cases, the evaluators 1 and 2 agreed with the gold standard in 17 and 14 cases, respectively. The concordance between gold

standard and the 2 evaluators was calculated using Cohen's Kappa coefficient, which measures the extent of agreement between gold standard diagnosis and remote evaluation, adjusted for the agreement expected by chance. For evaluator 1 and evaluator 2 was obtained $k = 0.863$ and $k = 0.648$ respectively (both with statistical significance $p=0.000$). The Cohen's Kappa coefficient between both evaluators in remote diagnosing was $k = 0.795$ (statistical significance $p=0.000$).³²

These results show a very good agreement ($0.8 \leq k \leq 1$) and a good agreement ($0.6 \leq k < 0.8$), respectively for evaluator 1 and for evaluator 2, in diagnosing between clinical oral examination and photographs from the rORAL-review, supporting the use of rORAL. Moreover, the good agreement between diagnoses made by the evaluators stresses, at least for the clinical cases in this study, the feasibility of rORAL in screening processes.

The dentists enrolled in this pilot study agreed that rORAL could facilitate the early diagnosis of oral diseases in elderly people at day care centers and that it was easy to use. rORAL was also used in the education environment. Through rORAL-review, students had the possibility to explore the photographs of the clinical cases recorded and the functionalities available. In this context, students and faculty had the opinion that rORAL could be useful in the learning process as it allows the access to more clinical cases and they can review them several times.

³² Statistical measures were computed using the software IBM SPSS Statistics (version 24)

6.2 - System Usability Evaluation

There are several ways to get feedback from users. For this pilot study, the System Usability Scale (SUS)³³ was chosen. SUS was invented by John Brooke in 1986 and since then it has become a very popular tool to measure a system's usability. It consists in 10 questions answered with a Likert scale that ranges from 1 to 5, or from Strongly Disagree to Strongly Agree. The following aspects strongly contribute to the popularity of SUS:

- it can be easily adapted to any system since it is quite general;
- is very easy for the users to answer (is short and the users must mark their response straight away rather than thinking a lot about each question);
- is a quick, cheap and accurate way to evaluate the usability when there is only a small set of users;

After having the questionnaires filled, the usability score is counted. The score 68 (out of 100 points) is the average usability score.

A European Portuguese version of the SUS questionnaire was used [39] and two questionnaires were made, both anonymous. One for the mobile app, rORAL-mob, and another for the web-based Cases Review and Evaluation portal, rORAL-review. Both questionnaire models are presented in Annex 2: SUS Questionnaires.

The procedure for the collection of the answers to the questionnaires was the following. For rORAL-mob, 5 dental assistants and 1 dentist were asked to use the app to create clinical cases for patients, take photographs of their oral cavities and upload them to the backend. After that, they were given the questionnaire and filled it. For rORAL-review, 2 dentists and 5 students assessed the cases (described in 6.1 – Pilot Study) and filled the questionnaire.

The SUS score was counted for each of the questionnaires filled and was grouped by subsystem. The scores for rORAL-mob and for rORAL-review are presented in Table 17 and Table 18, respectively.

³³ <https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html>

PARTICIPANT	SCORE
1	85
2	60
3	47,5
4	72,5
5	92,5
6	77,5
AVERAGE	72,5
STD DEVIATION	16,5

Table 17 - SUS scores for rORAL-mob.

The SUS scores for rORAL-mob, shown in Table 17, show that generally users considered the usability of the app to be slightly above average. However, the scores had a high variation, with two users giving very high grades while other two gave very bad grades.

PARTICIPANT	SCORE
1	80
2	80
3	85
4	85
5	85
6	82,5
7	70
AVERAGE	81
STD DEVIATION	5,4

Table 18 - SUS scores for rORAL-review.

The SUS scores for rORAL-review, shown in Table 18, show that generally users considered it very usable. Six out of seven users gave a SUS score of 80 or above, which is high and above the universal average score of 68.

By looking at the SUS scores for rORAL-mob and for rORAL-review, we can conclude that the users deemed the system to be effective, satisfactory and easy to use.

Chapter 7

Conclusions and Future Work

7.1 - Conclusions

The main objective of this work was to build a system capable of taking photographs of the oral cavity and share them to a platform where they could be seen and reviewed, supporting workflows that can be used in teledentistry. Some of these workflows regard the use of teledentistry in medical education and the use of teledentistry in screening.

Both scenarios were tested. A pilot study was performed with dental medicine students and with dentists. The students and the faculty stated that rORAL could be useful in the learning process because it allowed the students to access more clinical cases, which they can review. Both students and dentists were also given two different questionnaires to fill regarding the usability of the system. The grades of those questionnaires revealed that they found rORAL, in general, to be useful, easy to use, and that they would see themselves using it in the future.

The outcomes support the usability of the rORAL platform, and the dentists enrolled in the pilot study agreed that it could be a feasible tool to use in screening processes. The positive results sustain the use of rORAL in education and in population screenings, successfully promoting the use of teledentistry.

Although other platforms have been implemented for the remote assessment of images in oral care, their use for educational purposes was not documented. This work shows through the pilot study that there is an opportunity for using remote assessment of oral images in dental education.

The developed system, besides fulfilling its purpose, was used in a real scenario with great acceptance. Dentists agreed that rORAL could help in screening and early diagnosis of oral diseases in the elderly at day care centers. The use of rORAL in such scenario grants oral diseases prevention, which has high impact upon the society and the individual. This demand is even more important considering the reduced mobility that commonly affects the elderly.

7.2 - Future work

The work presented in this dissertation is not completed. Although a prototype was built, tested and validated, it is still not ready for production stage and it can be enhanced. Indeed, more work and tests need to be done before aiming at bigger goals.

During the pilot study, the evaluators used different terminology to describe the same diagnosis. So, to prevent redundancy, it is advisable to restrict each diagnosis to a unique terminology. Therefore, the adoption of International Classification of Diseases, 10th Revision, Clinical Modification (ICD-10-CM)³⁴ is suggested as a further improvement of rORAL-review to restrict the terminology in evaluations.

The use of an external camera, for example an action camera, to take oral photographs was tried. It was tested during development, however, due to limitations of equipment availability, it was not tested in the pilot study. It would be interesting, as future work, to develop the external camera integration in the rORAL-mob and to test it further with the users of the system.

In the early stages of rORAL some research was made on how to automatically improve image quality, for example, enhancement of specific parts of the photographs relevant for oral care, and brightness correction. Although the initial idea was not pursued, it would still be worthwhile to try to automatically perform image enhancement on the photographs taken, even more when the quality of the photographs taken is crucial for the accuracy of the evaluations.

Although Android is the leading mobile operating system worldwide, iOS also has a considerable share of the market, so an iOS version of the app would bring it to more people, expanding the user base of rORAL.

Tests with more users are needed. With what concerns the system reliability, although the pilot study allows interesting and satisfactory agreement with the gold standard, more clinical cases would help to evaluate the feasibility of the system under several diagnoses. With respect to the usability of the system, the SUS was used to fulfill this purpose. However, SUS is a quite generic test thus it did not allow us to extract specific information on what exactly the users felt while using the system. To accomplish that, further tests should also focus on what users think about each functionality of the system and what new functionalities they want it to have.

³⁴ <http://www.who.int/classifications/icd/icdonlineversions/en/>

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Annex 1: Use Cases Description

rORAL-mob use cases

This section is about the objectives that users of the system may have regarding rORAL-mob.

Use case 1: Join a Study

Use case description: An Operator can join a study previously created by a Point of Contact, as long as they are given the QR Code or id/password for it.

Application: rORAL-mob

Actor: Operator

Preconditions:

- Operator is logged in the mobile application
- Smartphone is connected to the internet

Postcondition:

- Operator can now work in that Study

Basic flow:

- 1 – Operator goes to the Studies screen
- 2 – Operator selects 'Check-in in a new study'
- 3 – Mobile application prompts the Study's credentials
- 4 – Operator inserts the Study's ID and PIN
- 5a – Mobile application validates the credentials
- 5a2 – Mobile application displays a success message

Alternative flow:

- 4a – Operator scans the Study's QR code
- 4a2 – the use case continues from step 5a

Exception flow:

- 5b – Mobile application doesn't validate the credentials
- 5b2 – Mobile application displays an error message
- 5b3 – the use case ends

Use case 2: Create Patients for a Study

Use case description: An Operator can create a Patient and its information, like name, gender and date of birth, and assign it to a Study.

Application: rORAL-mob

Actor: Operator

Preconditions:

- Operator is logged in the mobile application
- Operator has joined the Study in which they intend to create a Patient

Postcondition:

- Patient is created, associated with that Study and ready for Episodes to be captured

Basic flow:

- 1 – Operator goes to the Studies screen
- 2 – Operator selects the Study in which they intend to create a Patient
- 3 – Operator selects 'Add Patient'
- 4 – Mobile application prompts the Patient's information (name, unique ID, gender and birthdate)
- 5 – Operator enters the Patient's information
- 6a – Mobile application validates the Patient's information
- 6a2 – Mobile application displays a success message

Exception flow:

- 6b – Mobile application doesn't validate the Patient's information
- 6b2 – Mobile application displays error messages
- 6b3 – the use case returns to step 4

Use case 3: Take Photographs of a Patient (Episode)

Use case description: An Operator can take Photographs of a Patient previously created by them, making an Episode.

Application: rORAL-mob

Actor: Operator

Preconditions:

- Operator is logged in the mobile application
- Operator has joined the Study in which they intend to create a Patient
- Operator has created the Patient for which they intend to create an Episode

Postcondition:

- Episode was created and Photographs were taken

Basic flow:

- 1 – Operator goes to the Studies screen
- 2 – Operator selects the Study in which they intend to create an Episode
- 3 – Operator selects the Patient in which they intend to create an Episode
- 4 – Operator selects 'New Episode'
- 5 – Operator takes a new Photograph (this step can be repeated several times)
- 6 – Operator selects 'Stop Episode'

Use case 4: Submit an Episode for evaluation

Use case description: An Operator can upload the Episode's Photographs to the server, where they will be awaiting evaluation by an Evaluator.

Application: rORAL-mob

Actor: Operator

Preconditions:

- Operator is logged in the mobile application
- There is at least one Episode in the mobile application
- Smartphone is connected to the internet

Postcondition:

- Episode was uploaded to the remote server where it awaits evaluation

Basic flow:

- 1 – Operator goes to the Studies screen
- 2 – Operator selects the Study in which that Episode belongs to
- 3 – Operator selects the Patient in which that Episode belongs to
- 4 – Operator selects the Episode they wish to submit for evaluation
- 5 – Operator selects the Upload option
- 6 – Operator selects the priority
- 7a – Mobile application uploads the Episode to the remote server
- 7a2 – Mobile application displays a success message

Alternate flows:

- 3a – Operator selects the Episode they wish to submit for evaluation
- 3a2 – the use case continues from step 5

Exception flow:

- 7b – Mobile application doesn't successfully upload the Episode to the remote server
- 7b2 – Mobile application displays an error message
- 7b3 – the use case ends

Use case 5: Check an Episode's evaluations

Use case description: An Operator receives in the app the evaluations submitted by the evaluators for the episodes they have submitted.

Application: rORAL-mob

Actor: Operator

Preconditions:

- Operator is logged in the mobile application
- There is at least one Episode in the mobile application
- Smartphone is connected to the internet

Basic flow:

- 1 – Operator goes to the Studies screen
- 2 – Operator selects the Study in which that Episode belongs to
- 3 – Operator selects the Patient in which that Episode belongs to
- 4 – Operator selects the Episode they wish to check for evaluations
- 5 – Mobile application fetches that Episode's evaluations from the remote server and presents them to the Operator

Exception flow:

- 5a – Mobile application doesn't successfully fetch the Episode's evaluations from the remote server
- 5a2 – Mobile application displays error message
- 5a3 – the use case ends

rORAL-PoC use cases

This section is about the objectives that users of the system may have regarding rORAL-PoC.

Use case 6: Create a Study

Use case description: A Point of Contact can create a Study, give it a name and a description.

Application: rORAL-PoC

Actor: Point of Contact

Preconditions:

- Point of Contact is logged in the website

Postcondition:

- Study was created and is ready to gather work

Basic Flow:

- 1 – Point of Contact goes to the Studies screen
- 2 – Point of Contact selects 'Add Study'
- 3 – Website prompts the Study's name, description and PIN
- 4 – Point of Contact enters the Study's information
- 5 – Website validates the Study's information
- 5a2 – Website displays a success message

Exception flow:

- 5b – Website doesn't validate the Study's information
- 5b2 – Website displays an error message
- 5b3 – The use case returns to step 2

Use case 7: Register an Evaluator

Use case description: A Point of Contact can register an Evaluator into their own Domain.

Application: rORAL-PoC

Actor: Point of Contact

Preconditions:

- Point of Contact is logged in the website

Postcondition:

- Evaluator is registered and can check their Domain's Episodes and submit evaluations for them

Basic flow:

- 1 – Point of Contact goes to the Evaluators screen
- 2 – Point of Contact selects 'Add Evaluator'
- 3 – Website prompts the Evaluator's username and email address
- 4 – Point of Contact enters the Evaluator's information
- 5 – Website validates the Evaluator's information
- 5a2 – Website displays a success message

Exception flow:

- 5b – Website doesn't validate the Evaluator's information
- 5b2 – Website displays an error message
- 5b3 – The use case returns to step 2

Use case 8: Check the work done by the Evaluators

Use case description: A Point of Contact can check an ordered list with the latest work done by the Evaluators registered in their own Domain.

Application: rORAL-PoC

Actor: Point of Contact

Precondition:

- Point of Contact is logged in the website

Basic flow:

- 1 – Point of Contact goes to the Evaluators screen
- 2 – Point of Contact selects the Evaluator whose work they want to check
- 3 – Website displays the Evaluator's checked out Episodes and whether they have been evaluated or not

rORAL-review use cases

This section is about the objectives that users of the system may have regarding rORAL-review.

Use case 9: See the list of Episodes waiting for Evaluation

Use case description: An Evaluator can see a list of the Episodes waiting for Evaluation.

Application: rORAL-review

Actor: Evaluator

Preconditions:

- Evaluator is logged in the website

Basic flow:

- 1 – Evaluator goes to the Episodes Waiting for Checkout screen
- 2 – Website displays the Episodes waiting for Evaluation

Alternate flows:

- 1a – Evaluator goes to the Studies screen
- 1a2 – Evaluator selects a Study with work available
- 1a3 – Evaluator selects a Patient with work available
- 1a4 – Website displays and highlights Episodes waiting for Evaluation

1b – Evaluator goes to the Checked Out Episodes screen

1b2 – The use case continues from step 2

Use case 10: Evaluate an Episode

Use case description: An Evaluator can evaluate an Episode, whose Operator is notified about.

Application: rORAL-review

Actor: Evaluator

Preconditions:

- Evaluator is logged in the website
- There is at least one Episode waiting for Evaluation

Postcondition:

- Evaluation is submitted and the Operator who created the Episode is notified

Basic flow:

- 1 – Evaluator goes to the Episodes Waiting for Checkout screen
- 2 – Evaluator selects the Episode they want to evaluate
- 3 – Evaluator selects 'Checkout'
- 4 – Evaluator fills the form and selects 'Submit Evaluation'
- 5a – Website validates the Evaluation
- 5a2 – Website displays a success message

Alternate flows:

- 1a – Evaluator goes to the Studies screen
- 1a2 – Evaluator selects a Study with work available
- 1a3 – Evaluator selects a Patient with work available
- 1a4 – Evaluator selects an Episode waiting for Evaluation
- 1a5 – The use case continues from step 3
- 1b – Evaluator goes to the Checked Out Episodes screen
- 1b2 – Evaluator selects the Episode they want to evaluate
- 1b3 – The use case continues from step 4

Exception flow:

- 5b – Website doesn't validate the Evaluation
- 5b2 – Website displays an error message
- 5b3 – The use case returns to step 4

Use case 11: Ask for other Evaluators to evaluate an Episode

Use case description: An Evaluator can ask for a second opinion from any other Evaluator regarding an Episode that they are working on.

Application: rORAL-review

Actor: Evaluator

Preconditions:

- Evaluator is logged in the website
- Evaluator has at least one Episode checked out

Postcondition:

- Episode gets shown to Evaluators looking for new Episodes to evaluate, stating that a new opinion is asked for that Episode

Basic flow:

- 1 – Evaluator goes to the Checked Out Episodes screen
- 2 – Evaluator selects the Episode to which they want to request a second opinion
- 3 – Evaluator selects 'Request Second Opinion'

Alternate flows:

- 1b – Evaluator goes to the Evaluated Episodes screen
- 1b2 – Evaluator selects the Episode to which they want to request a second opinion
- 1b3 – The use case continues from step 3

Annex 2: SUS Questionnaires

In this section there are the questionnaires that were given to the users of the pilot study upon completion of their tasks. Since the questionnaire for rORAL-mob and the questionnaire for rORAL-review are very similar, only one of them is shown. The questionnaire is in Portuguese because it was the mother tongue of the pilot study's participants.

Avaliação da usabilidade da aplicação móvel

O objetivo das perguntas seguintes é entender a percepção que o utilizador tem sobre a facilidade de uso da aplicação móvel. Os resultados vão servir para avaliar a mesma e decidir sobre possíveis alterações na maneira como ela se relaciona com o utilizador.

	Discordo totalmente					Concordo totalmente
1. Acho que gostaria de utilizar esta app com frequência.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
2. Considerei a app mais complexa do que necessário.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
3. Achei a app fácil de utilizar.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
4. Acho que necessitaria de ajuda de um técnico para conseguir utilizar esta app.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
5. Considerei que as várias funcionalidades desta app estavam bem integradas.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	
6. Achei que esta app tinha muitas inconsistências.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
	1	2	3	4	5	

7. Suponho que a maioria das pessoas aprenderia a utilizar rapidamente esta app.

1	2	3	4	5

8. Considerarei a app muito complicada de utilizar.

1	2	3	4	5

9. Senti-me muito confiante a utilizar a app.

1	2	3	4	5

10. Tive que aprender muito antes de conseguir lidar com esta app.

1	2	3	4	5

Obrigado pela resposta